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DATE: July 1, 1955

SUBJECT: RESEARCH PROGRAM AND OPERATING EXPERIENCE ON ORNL REACTORS

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Session P.1.2

RESEARCH PROGRAM AND OPERATING EXPERIENCE

ON ORNL REACTORS

By

M. E. Ramsey - Oak Ridge National Laboratory
C. D. Cagle - Oak Ridge National Laboratory

INTRODUCTION

The research programs at the Oak Ridge National Laboratory which make use of reactors or reactor products primarily use the two general-purpose research reactors. These are the normal-uranium, graphite-moderated reactor and the Low Intensity Testing Reactor. It is interesting that neither of these were built expressly as long term research reactors but have been adapted to this usage.

The research work involving usage of these reactors covers a wide range of fields in both pure and applied research including the following: basic studies of neutron and radiation properties, solid state structure and phase transitions by use of neutron spectroscopy, radiation damage of materials, radiation effects in chemistry, radioactivation analyses of trace impurities, biological effects of radiation, reactor development, and radiation monitoring development.

Another important usage of these reactors is the preparation of radioisotopes for world-wide usage.

Training of personnel in reactor technology is another important phase of the work. Two programs are devoted to this work. One is the Oak Ridge Institute of Nuclear Studies (ORINS) which concentrates on the uses of radioisotopes. The other is the Oak Ridge School of Reactor Technology which teaches the principles of reactor theory, design, and usage. In addition to these formal programs, faculty members from universities all over the United States do special research work at the reactors especially during the summer months.

This report describes these reactors and the research facilities available.

GRAPHITE REACTOR

The Oak Ridge National Laboratory's graphite-moderated, air-cooled, normal uranium reactor (figures 1 and 2) was built as the pilot plant for the plutonium-producing reactors which are at Hanford, Washington. Construction was started early in 1943, and critical loading was completed on November 4, 1943. This was the first reactor built that could be cooled and thereby operated at a reasonably high power level for long periods of time and was the second reactor built in this country. It was designed to operate at one megawatt power level, and its prime purposes were to furnish operating experience, reactor characteristics, and to provide small quantities of plutonium to aid in the development of chemical separation techniques to be used at Hanford. Since this is an air-cooled reactor, water-cooled fuel tubes of the Hanford type were simulated in some of the 4"-square test holes.

The reactor core and reflector is a 24' cube of graphite built up of 4" square by 50" long blocks and contains 1248 fuel channels that are 1 3/4" squares with the diagonals vertical and horizontal. Also there are 22 horizontal 4" square holes that go all the way through and six that go half way through the graphite perpendicular to and between the fuel channels. Six vertical 4"-square holes penetrate to a depth of 17'-4" into the graphite. Ten instrument openings penetrate the shield up to the graphite. Two thermal column openings, two 14"-square biological specimen entrances, four 1.68" diameter holes through the central core, and a foil slot through the reactor center make up the remainder of the experiment facility openings. See Table I.

TABLE I

RESEARCH OPENINGS INTO GRAPHITE REACTOR

Kind of Facility	Number of Facilities	Maximum Thermal Neutron Flux	In-Cd Ratio	Gamma	Approximate Temperature
4-inch square horizontal	42 openings	3.6×10^{11} to 1×10^{12}	20	3×10^5 to 8×10^5 R/hr	35°C to 160°C
4-inch square vertical	3	8×10^{11}	20	6.7×10^5 R/hr	135°C to 140°C
1.68-inch diameter horizontal	4	1×10^{12}	20	9×10^5 R/hr	35°C
2 3/4 in. x 3/8 in. foil slot	1	1.1×10^{12}	20	9×10^5 R/hr	160°C

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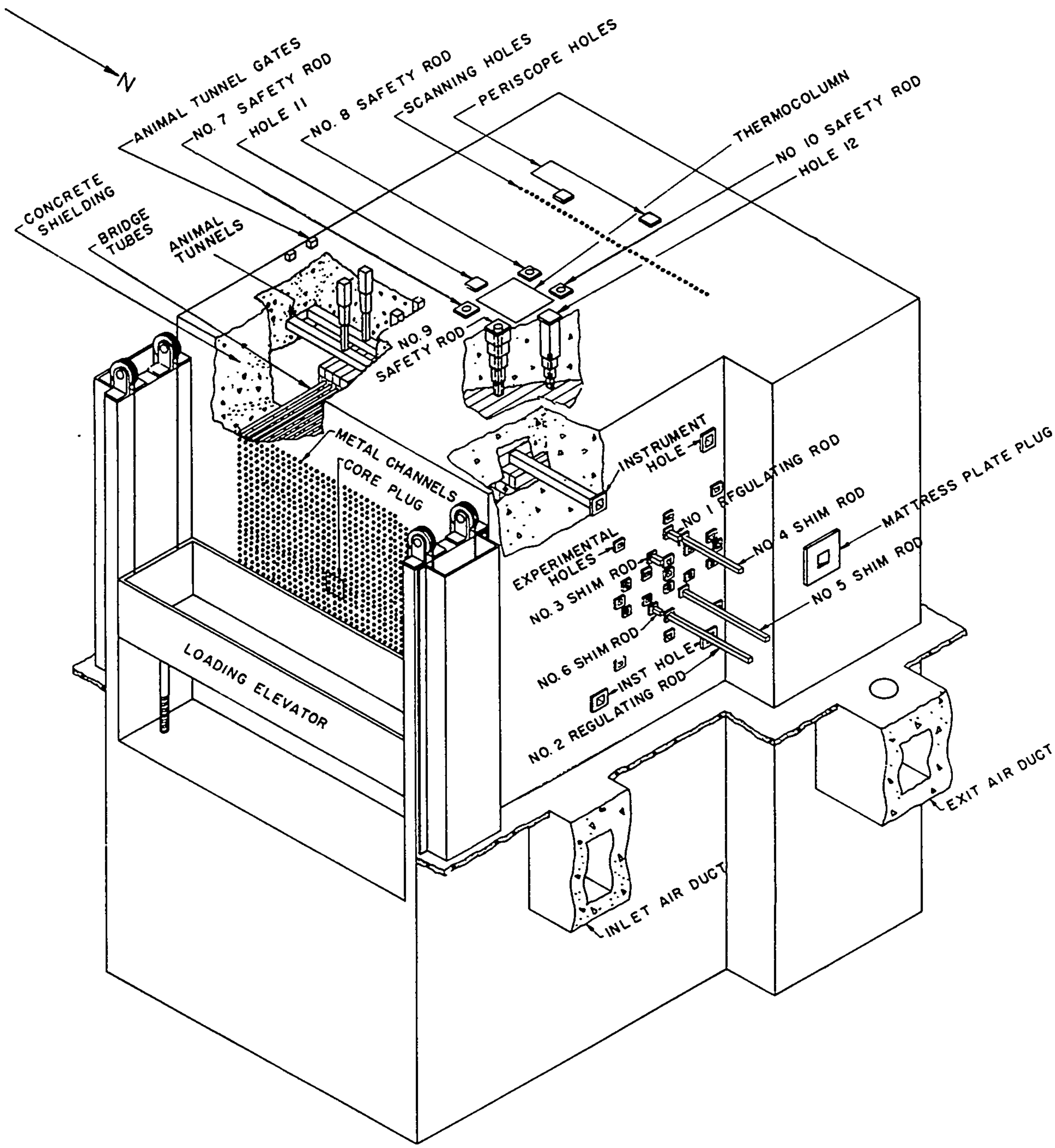

Fig. 1. A Cutaway Sketch of the Normal-Uranium, Graphite-Moderated Reactor

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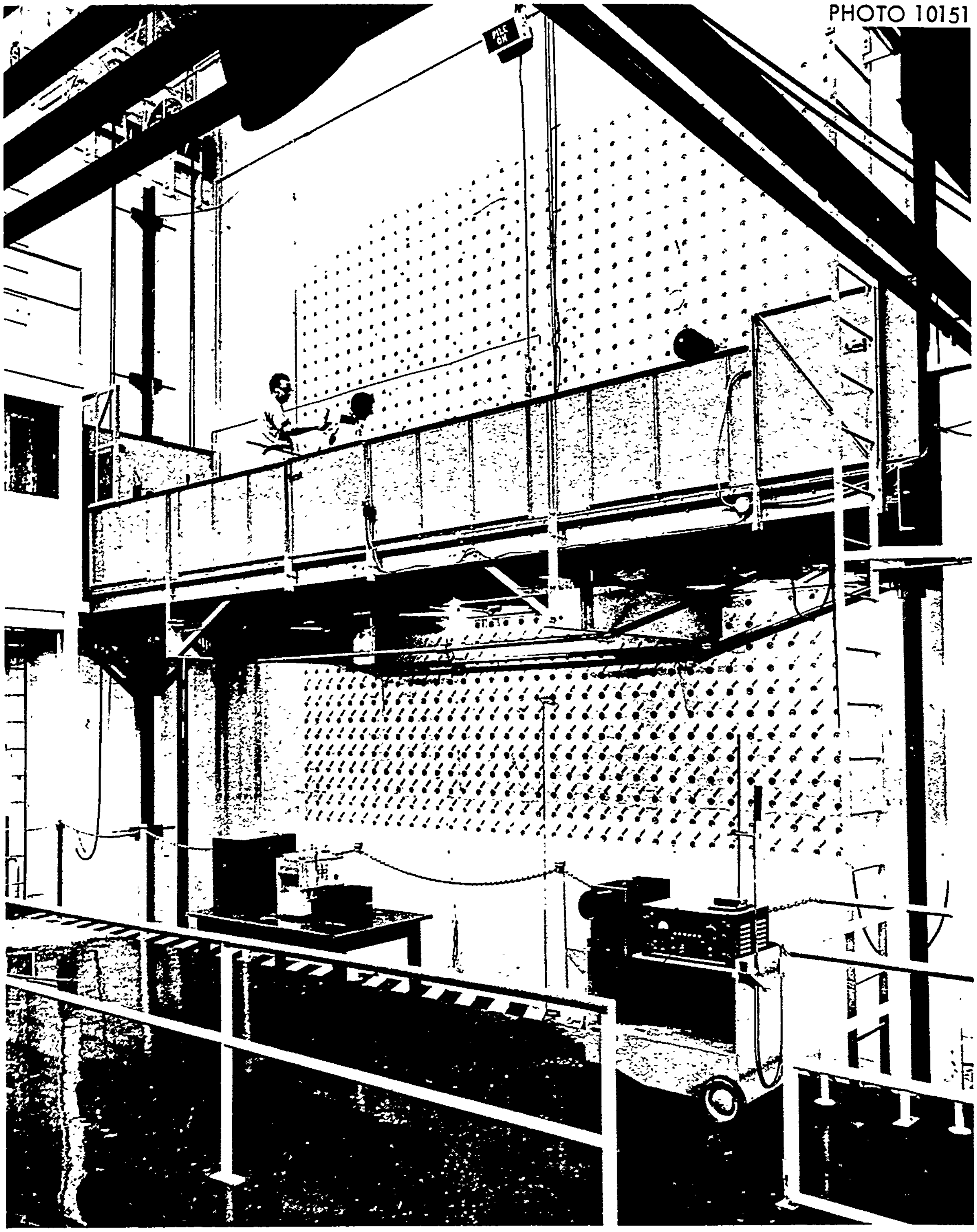

Fig. 2. Fuel-Charging Side of the Graphite Reactor.

TABLE I (CONT'D)

Kind of Facility	Number of Facilities	Maximum Thermal Neutron Flux	In-Cd Ratio	Gamma	Approximate Temperature
Unused fuel channels in core region	5	5.5×10^{11} to 1×10^{12}	20	4.5×10^5 to 9×10^5 R/hr	35°C
Unused fuel channels in reflector region	418	10^{10} to 3×10^{11}		10^4 to 3×10^5 R/hr	30°C to 40°C
14-in. square biological tunnel lead-lined	1	1.3×10^9	~70 Mn-Cd ratio	200 R/hr	25°C to 35°C
14-in. square biological tunnel bare	1	5×10^8	73 Mn-Cd ratio	3.4×10^3 R/hr	25°C to 35°C
5-foot square vertical thermal column	1	1.5×10^7	$\sim 10^6$	135 R/hr at top of column	Room Temperature
2½-foot square horizontal thermal column	1	5×10^9	130	1.2×10^4 R/hr	Room Temperature
Unused 9-inch square ionization chamber holes	2	10^7 to 10^9	~70 Mn-Cd ratio	$\sim 5 \times 10^3$ R/hr	35°C

The reactor shield is a 7-foot thickness of concrete that surrounds the core with manifold spaces provided for the cooling air. Plugged sleeves set into the concrete provide access to the holes through the graphite. The inner-most and outer-most 1-foot thicknesses of the shield are normal structural concrete and aggregate and contains web-type steel reinforcing. The space between is filled with a special concrete mixture containing haydites, an expanded clay, to retain about 10% of the make-up moisture as neutron shielding and barytes aggregate to increase its density. The shield was overdesigned and is still more than adequate at the present higher power level. The reactor does not have a thermal shield, but the concrete is insulated to some degree from the graphite by layers of asbestos and cellamite. (See figure 3.) A 10-inch high air passage across the top of the core between the graphite and the concrete was designed into the reactor but was closed off shortly after operation started to deflect more air through the fuel channels when it was found to be unnecessary.

The reactor coolant is atmospheric air that makes one pass through and is discharged to the atmosphere through a 200-foot stack. In order to remove the heat at the present 3.5 megawatt operating level, 120,000 cubic feet per minute of air is drawn through by two 900-horsepower suction fans. Rough fiber glass filters remove dust particles from the air at the inlet to the system and a combination of fine fiber glass and asbestos paper filters remove radioactive particles picked up from the reactor before the air reaches the suction fans.

Five of the original eight shutdown rods are now in use; (See Table II) three were removed to provide for experiments since they proved to be unnecessary. Three of the remaining rods enter vertical 4" square holes from the top of the reactor. These rods are not of the original design. They are $3\frac{1}{2}$" square hollow steel shells 8 feet long that contain a layer of 1/16" thick cadmium in the walls and a shield plug in the upper end. They are attached to steel cables that can be wound up on a windlass operated by electric motors through an electromagnetic clutch. The brake that holds the rod up in the operating position is on the electric motor so that if the power to the electromagnetic clutch is lost either by electrical power failure or by intentional interruption as for a normal shutdown, the windlass is made free to turn and allows the rod to fall into the core by its own weight. Full fall requires little more than one second.

The other two shutdown rods are 1 3/4" square steel rods 200 inches long which contain 1.5% boron. They enter two of the horizontal 4" square holes which are sleeved down to 2" square with graphite. These two rods are driven by hydraulic motors for slow travel into or out of the reactor and can be made to travel the full distance into the reactor by a high pressure oil system within 4 seconds. This high pressure, 900 pounds per square inch, is maintained by two large weights pressing upon oil-filled cylinders and is kept from the drive mechanisms by normally open solenoid valves so that, if the electrical power fails or is interrupted by the shutdown switch, the valves open and allow the 900 psi pressure to hit pistons which operate rack and pinion drives to push the rods into the reactor.

Two other rods, identical to the hydraulic rods are used as regulating rods when the reactor is being operated manually. They are driven by electric motors and are not part of the shutdown system. Both rods have a fast speed in and out and one has a slow speed for fine control.

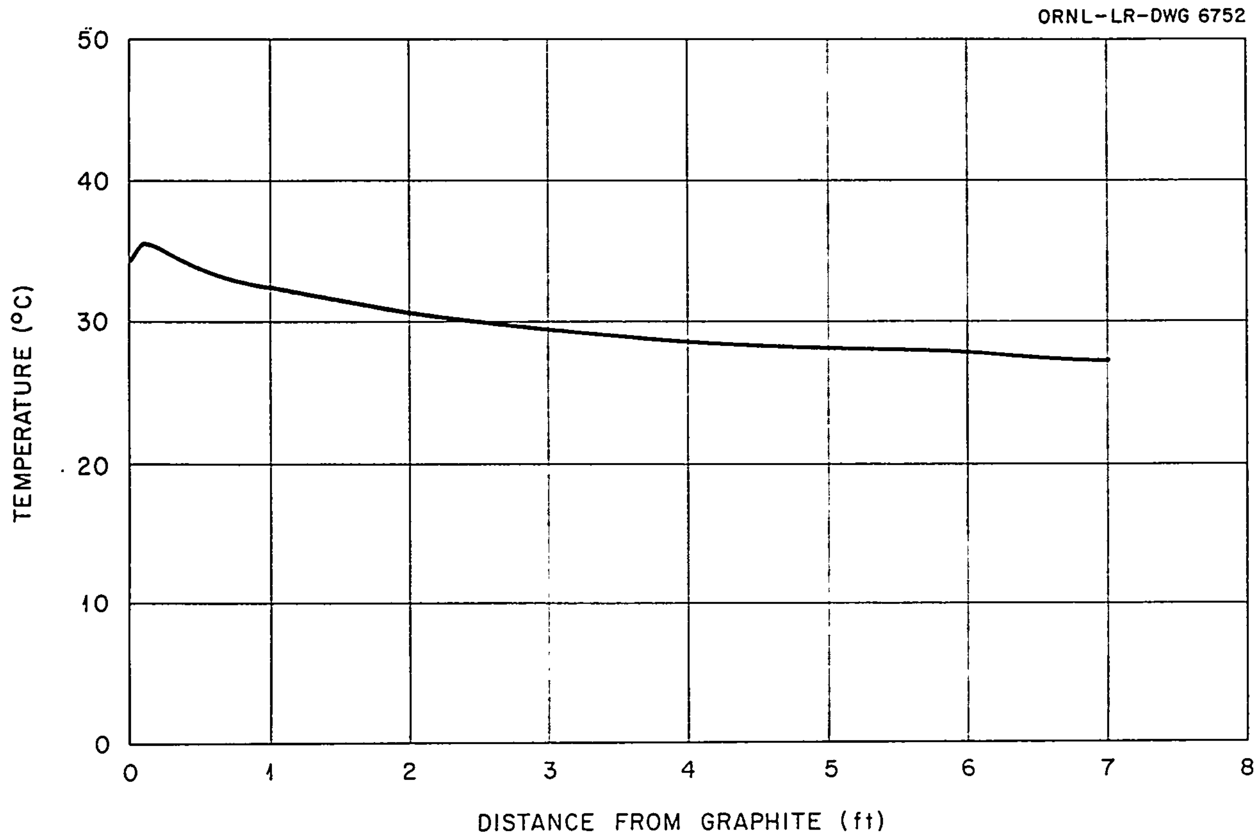

Fig. 3. Temperature Traverse Through the Concrete Shield of the Graphite Reactor Showing that Gamma Heating is not Excessive nor is the Temperature Differential Through the Shield Great Enough to Cause Severe Stresses.

TABLE II

CHARACTERISTICS OF CONTROL AND SHUTDOWN RODS

Type of Rod	Control	Horizontal Shutdown	Vertical Shutdown
Number	2	2	3
Reactivity value	#1--0.57% $\frac{\Delta k}{k}$ #2--0.50% $\frac{\Delta k}{k}$	0.63% $\frac{\Delta k}{k}$	0.50% $\frac{\Delta k}{k}$
Material	1.5% boron steel	1.5% boron steel	Hollow steel shell containing layer of cadmium
Size and Shape	1.75 inch square bar 19 feet long	1.75 inch square bar 19 feet long	$3\frac{1}{2}$ inch square hollow steel shell 8 feet long. Top end contains lead and masonite shield and bottom end has spring shock absorber.
Method of operation	Direct electric motor driven.	Hydraulic cylinder operates rack and pinion drive. Normal operation --pump. Emergency operation--accumulator.	Gravity when latch solenoid is de-energized. Lifted out of reactor by electric motor.
Travel (Distance into Reactor)	In: To within 5 feet of opposite side of graphite. Out: To 1 foot outside graphite into concrete shield.	In: To within 5 feet of opposite side of graphite. Out: To 1 foot outside graphite into concrete shield.	In: 4 feet below and 4 feet above reactor center. Out: Just withdrawn from graphite.

TABLE II (CONT'D)

Speed of Travel	#1: Max. in 6.9 inches per second Max. out 6.9 inches per second #2: Max. in 4.76 inches per second Max. out 4.76 inches per second Min. in 0.044 inches per second Min. out 0.044 inches per second	In: Normal-- 6 inches per second Emergency--full travel in 4 seconds Out: 1 inch per second	In: $\sim$1 second for full fall. Out: $\sim$10 seconds.
Guide Tube	$2\frac{1}{4}$-inch x $2\frac{1}{4}$-inch square slot milled into graphite blocks in 4-inch square hole.	$2\frac{1}{4}$-inch x $2\frac{1}{4}$-inch square slot milled into blocks in 4-inch square hole.	Full size 4-inch square vertical hole.

Within recent months an automatic control system has been developed which uses one of the hydraulic rods in the nearly out position as its control rod. The electrically driven regulating rods are still used to position the automatic control rod within its operating range. This arrangement tends to minimize distortion of the neutron flux pattern within the reactor core.

Up until recently a boron shot tube was kept for emergency or disaster shutdown use. This consisted of a hopper of boron-steel shot that could be released into the reactor core region by pulling a cable in the control room to release a plug in the bottom of the hopper. The hopper was within the top shield of the reactor and could not be easily inspected. Also there was no way to test the working of the apparatus on a routine basis. By accident the pull cable was pulled recently and the shot did not fall into the reactor. They were found to be rusted and stuck together. Because of this, authorization has been given to completely remove the equipment since any safety equipment that cannot be periodically checked cannot be trusted to operate. All other safety features can be checked.

When operation of the graphite reactor was first started, very low level neutron flux during startup was monitored with a counter and then by a gamma compensated boron coated ionization chamber as the power level rose to the kilowatt level. The practice of using the neutron counter was discontinued and only the ionization chamber retained. This is safe because the fuel loading is kept such that the excess reactivity is below the delayed neutron contribution and prompt critical is an impossibility. Three of the gamma compensated chambers are now in use--one is read by a galvanometer and used for startup and manual operation, a second for the automatic control and the third for vernier control while in manual operation or as a spare. These chambers are located in the shield of the reactor where they "see" a neutron flux of about 10^8 n/cm^2-sec.

Three other non-gamma-compensated, boron-coated ionization chambers are used for the safety instrumentation to scram the reactor by way of electronic trips if the power level should be allowed to exceed 5.5 megawatts. It is not necessary that these chambers be gamma compensated because they are important only at a neutron level where the gamma contribution is negligible.

A second safeguard against power excursions is a system of boron-coated thermopiles whose composite signal which is proportional to the power level is fed to an electronic strip recorder containing a high level trip to initiate a scram at 6.0 megawatts.

The temperature of the aluminum jackets that enclose the uranium metal in the reactor must also be limited. This is accomplished by including in the loading fuel pieces having iron-constantin thermocouples attached to the jackets. Experience has shown that the hottest position in any fuel row is two feet past the center of the row in the direction of the air flow. At least forty such thermocouples are kept in the reactor at all times and positioned to give a good representation of the temperature distribution. The thermocouple having the highest reading supplies a signal to a single point strip recorder containing a high level trip to scram the reactor if the temperature exceeds 325°C. Actually the operator does not allow the temperature to exceed 280°C. It has been found that a standard power level of 3.5 MW can generally be maintained year around without exceeding the safe temperature level.

The temperature of the graphite near (1 foot from) the center of the reactor is recorded but does not actuate any scram or alarm. Its value averages about 135°C.

Temperatures of the inlet and exit cooling air streams are measured for the purpose of heat power calculations by thermohms located in the inlet and exit air ducts. At one time the signal from a thermohm in the exit air duct was fed to a strip recorder containing a high level trip to cause a scram. The scram feature has been removed as unnecessary since the lag in this temperature is too long to be of value in the event of a power excursion, and it served no other purpose.

A pitot tube in the inlet air duct sends a signal to oil manometers at the control desk and to a ring-balance circular chart recorder which scrams the reactor if the air flow drops too low. Another ring balance recorder shows the pressure drop across the reactor from pressure taps located in the inlet duct and in the exhaust manifold. This recorder also scrams the reactor if its reading falls too low.

The radioactivity of the exhaust air from the reactor is measured by an ionization chamber through which a continuous sample of the air passes. The signal from this ionization chamber is read on a strip recorder at the control desk and until recently would actuate a scram if the normal radioactivity level increased by a factor of three. Experience has shown that the reactor itself could not cause such a condition unless it experienced a violent power excursion or great loss of air flow, conditions which, if they occurred, would initiate a scram. Also the off-gas from experiments and equipment at the Low Intensity Test Reactor have been tied into the graphite reactor exhaust and it would be pointless to shut down the graphite reactor because of radioactivity from some other source. In the course of one operating day the reactor generates a total of about 500 curies of radioargon (A^{41}) from the 0.9% argon present in the atmosphere. This is the major radioactivity in the exhaust air. There is a small amount of mixed fission product gases being evolved from small quantities of uranium oxide dust from defective fuel elements caught in cracks between graphite blocks.

The concrete shield at the exhaust end of the fuel channels would be damaged by the continual blast of hot air emerging from the channels if it were not protected. A one-inch thick wall of cellamite is spaced four inches from the inner face of the concrete to form a separate chamber which is cooled by a separate air stream. The pressure within this region as well as the air flow to it are monitored. If the negative pressure within the region becomes excessive, there is a possibility that the shield wall might collapse. To guard against this event, a negative pressure greater than 34" of water will cause the suction fans to be turned off. Loss of the fan suction shuts the reactor down by the other means described.

The hydraulic pressure accumulators which drive the horizontal shutdown rods into the reactor must be kept pumped up to contain a sufficient volume of oil at all times that the reactor is in operation. If a leak in the system should develop allowing the weights to fall to a minimum level, a switch actuated by the weight scrams the reactor while there is still enough oil left to accomplish the shutdown.

Frequently experiments are performed which can develop conditions which can injure personnel, the reactor, or expensive equipment if the reactor is not scrammed. Safeguard circuits from these experiments can be tied into the reactor scram circuits. Typical examples are:

1. One of the thermal column openings is shielded by a tank of water which, if accidentally drained, would allow about a 2-foot square beam of radiation to emerge from the reactor into a heavily frequented personnel area. To prevent this, a radiation monitor at the location scrams the reactor and sounds a siren.

2. A 4"-square horizontal hole contains a water-cooled hollow cylinder of enriched uranium aluminum alloy in which targets can be subjected to a high fast neutron flux. If the water flow were to fail the cylinder would probably melt and damage the reactor. The reactor is scrammed by a water flow recorder if the flow is lost.

3. A vertical 4" square hole is used to expose capsules containing test fuels for homogeneous reactors to check both solution stability and corrosion of the capsule walls. If the pressure in the capsule becomes excessive due to unexpected behavior, the capsule may rupture causing contamination of equipment or even personnel with fission products. To prevent this, a pressure monitor on the capsule scrams the reactor to stop the pressure buildup.

Manual scram switches are located at the control desk, the exit doors of the building, and at the experiment locations. The control console is shown in Figure 4.

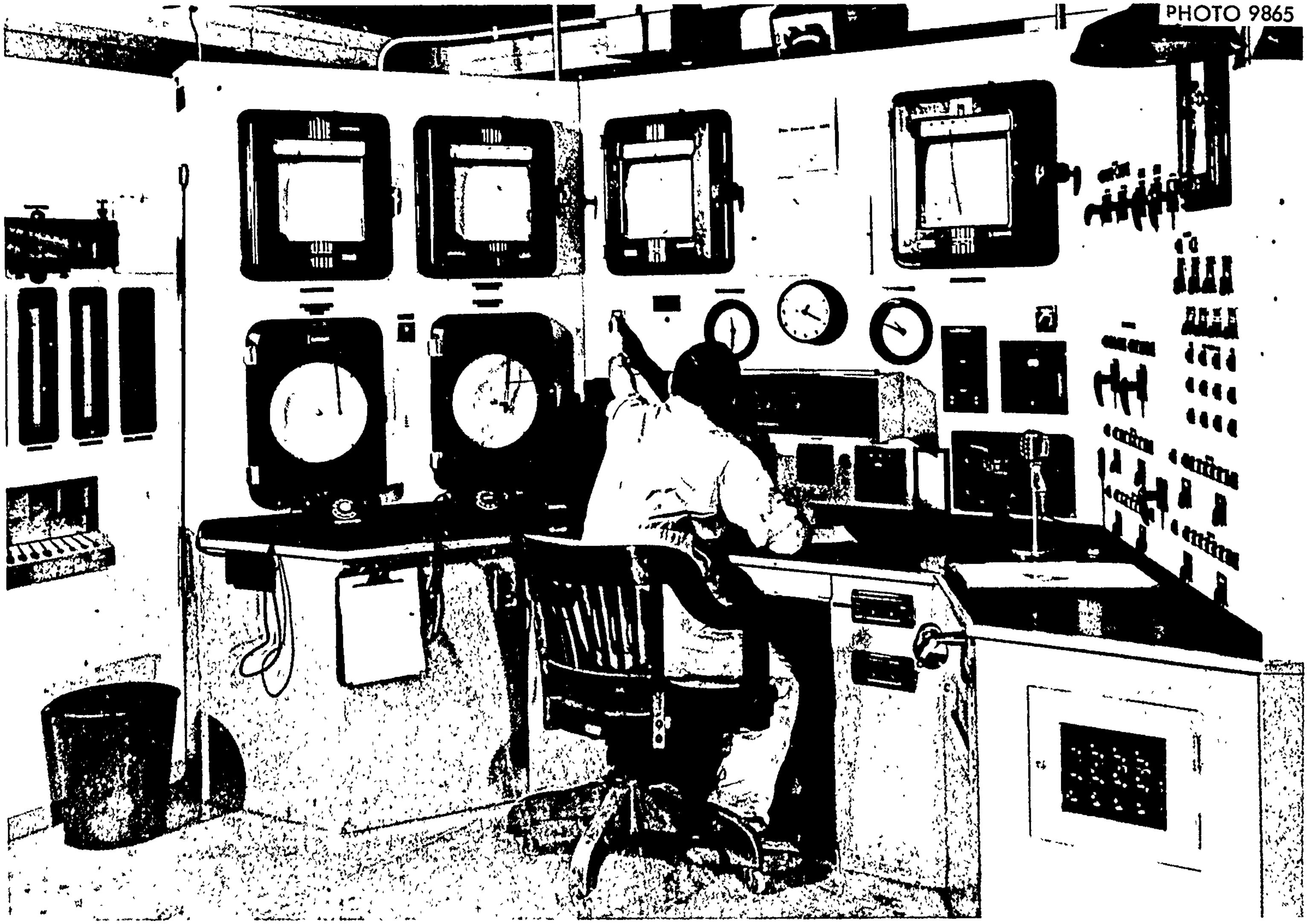

Fig. 4. Control Console of the Graphite Reactor Showing Operator Throwing "Scram" Switch to Shut the Reactor Down.

TABLE III

AUTOMATIC REACTOR SCRAM SUMMARY

Power level greater than 5.5 megawatts (ionization chambers)

Power level greater than 6.0 megawatts (boron-coated thermopiles)

Metal temperature greater than 325 ^{o}C

Air flow less than 40,000 cfm

Differential pressure across reactor less than 8 inches wg.

Radiation at horizontal thermal column greater than 50 mr/hr

Any experiment requiring that the reactor be shut down for safety reasons.

The reactor fuel is normal uranium metal in the form of 1.1 inch diameter by 4 inch long slugs encased in a 35-mil thick 2-S aluminum jacket. These are charged into the fuel channels end-to-end to simulate long rods. The purpose of the segmentation is for ease in handling. Each slug weighs about $2\frac{1}{2}$ pounds.

The fuel is inserted into the reactor by hand and positioned with measured rods while the reactor is shut down. Removal is accomplished by pushing it on through the graphite from which it falls through the air exhaust manifold to a chute which leads to a 20-foot deep water pit outside the reactor shield. See Figures 5 and 5a.

All during the operation of the reactor an annoying number of fuel element failures have occurred and two full scale attempts have been made to improve them. The first elements used were jacketed in 2-S aluminum cans having 20-mil thick walls, and the caps were sealed on by resistance welding. No bonding existed between the uranium and the aluminum. This type was used during 1943 and part of 1944. The next type had 35-mil thick 2-S aluminum walls with the caps arc-welded on in a helium atmosphere. Again the uranium and the aluminum were not bonded but were die-pressed to be in close contact. No failure of the first type of elements occurred but they were used only at low power and for only a short time. The second type came into use when the power level was increased from one megawatt to 3.6 megawatts. The failure rate of these elements was approximately one per month. Although this rate was not excessive enough to curtail operation, it did require constant vigilance to prevent damage to the reactor. The causes of failure were probably several, but the end result was always the same--bursting of the aluminum jacket allowing the rapid formation of uranium oxide which was carried away to some degree by the air stream causing contamination of the air exhaust system with fission products. The more serious result

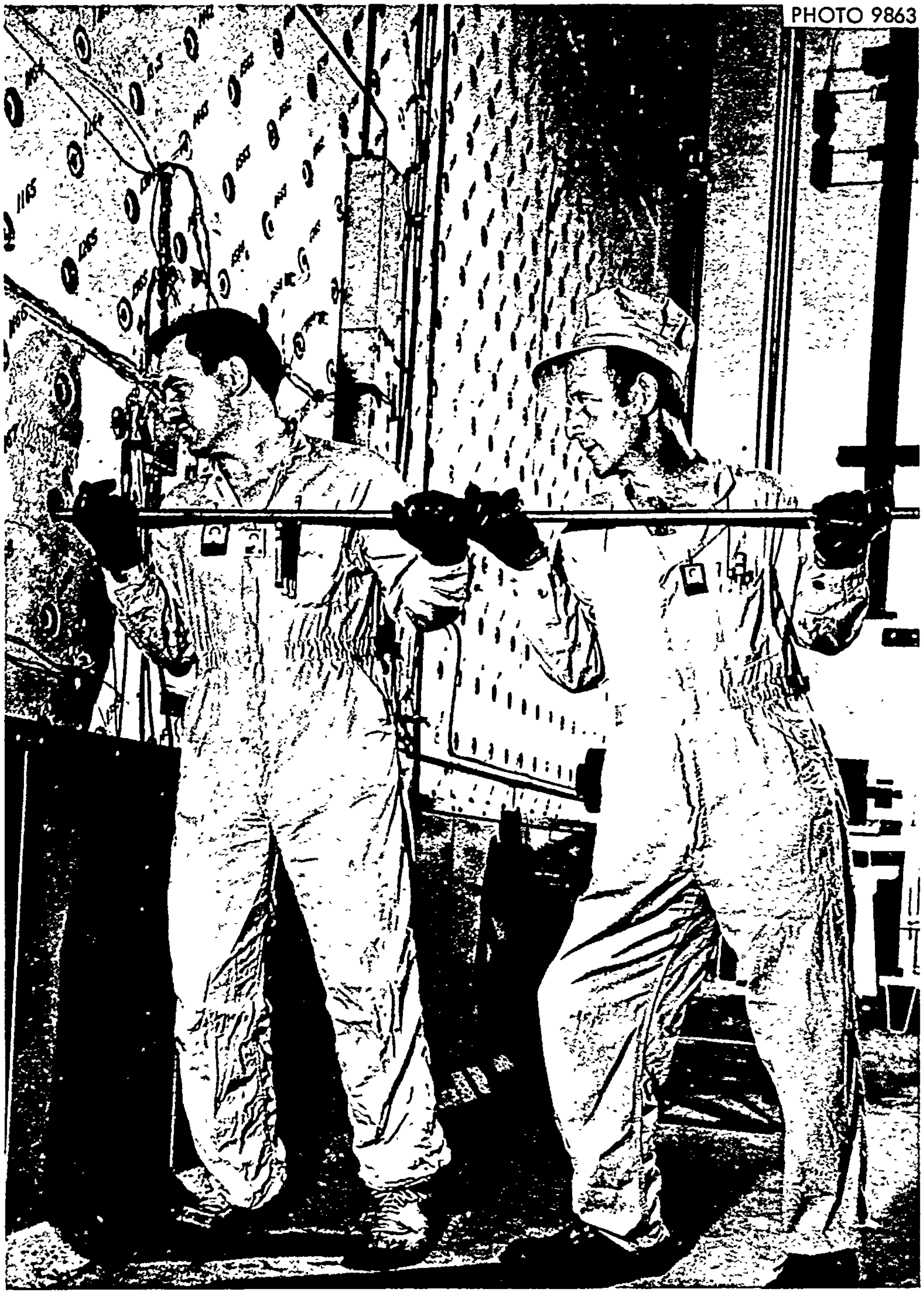

Fig. 5. A Closeup View of the Fuel Charging Face Showing Operators Pushing Fuel Elements from the Reactor Core.

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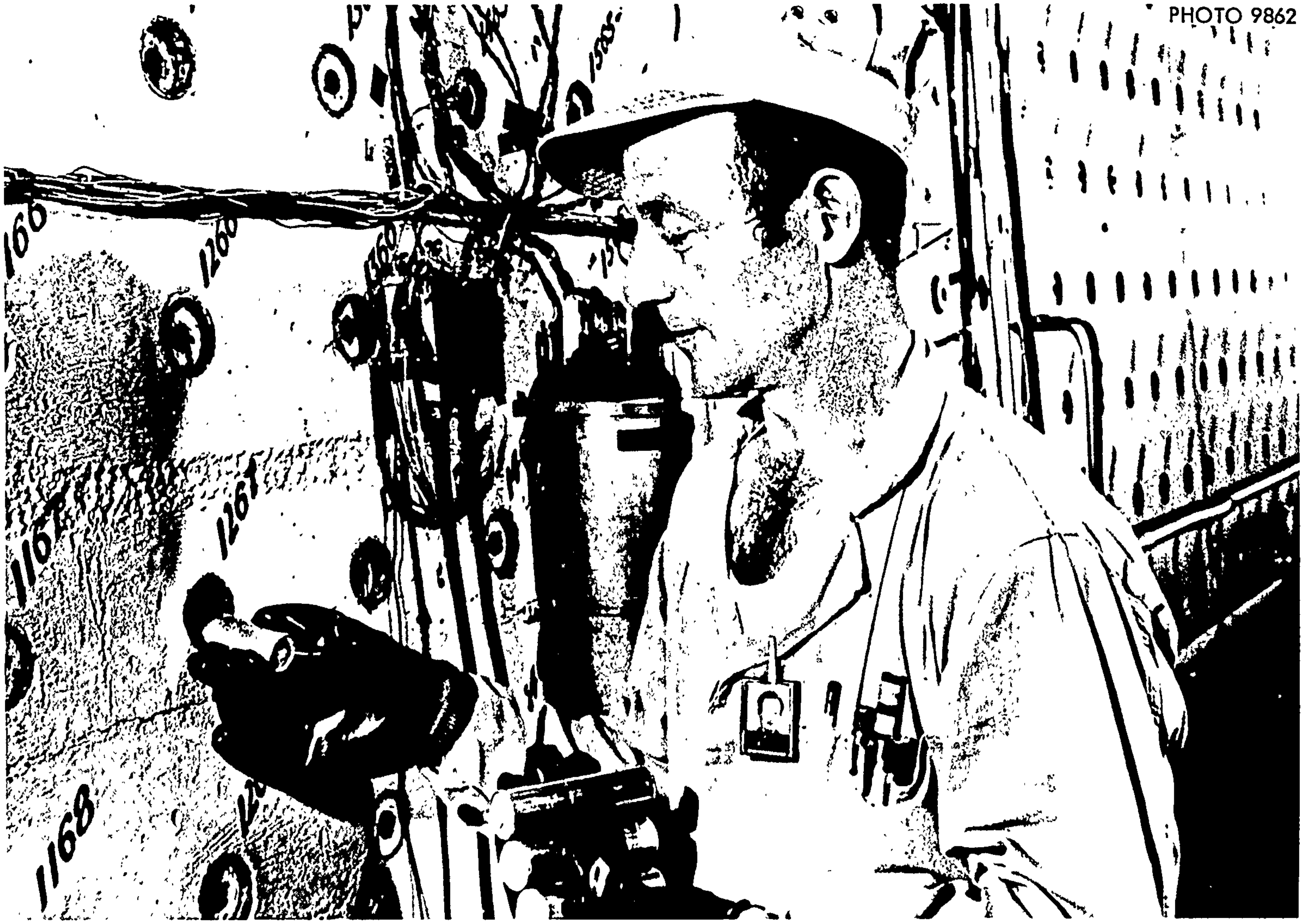

Fig. 5a. Operator Inserting Fuel Elements into a Fuel Channel. After being Inserted by Hand, They Are Centered in the Core by Pushing Them into Place with Measured Steel Rods.

of failure is the possible sealing off of the channel by the swelling element jacket as the oxide volume increases. When the air flow ceases, other elements in the channel fail due to high temperature. This has occurred twice, once in 1947 and again in 1948. The first instance involved 13 elements and the second 5 elements. In both instances the fuel channel was so scarred by the discharging techniques that had to be used that they were not suitable for further use as fuel channels and were diverted to other usages. Since that time a weekly inspection of all fuel channels has prevented the recurrence of such multiple failures.

During 1952 the fuel was changed to a bonded type. This bond is an aluminum-silicon eutectic which fills the space between the aluminum jacket and the uranium metal. Its purpose is to separate the uranium from the aluminum and still provide good heat transfer. It also tends to slow the rate of a failure by minimizing the area of uranium that might be exposed to air if a tiny hole should develop in the aluminum jacket. Since one of the causes of failure in the unbonded elements was interaction between the uranium and the aluminum if the temperature were in the 200° to 300° range for long periods, it was hoped that the bonded elements could be operated above this temperature allowing the power level to be increased. This, however, has not proved to be true; the element jackets are now operating at a higher temperature relative to power level than before due to the better heat transfer from the uranium to the aluminum jacket through the bond under the thermocouple bead and failures occur at an objectionable rate above 300°C indicating that there is still sufficient contact between the aluminum and the uranium to cause trouble. With the unbonded elements the jacket temperature could be operated continuously at 245°C without experiencing serious failure rates. The power level at this temperature averaged 3.6 megawatts with frequent operation at 4.0 megawatts. With the bonded elements, experience has shown that 285°C as shown by the thermocouple should not be exceeded for long periods. The average power level now is 3.5 megawatts to stay below this limit. The gain has been only in the frequency of failure rate which is less than half that with the unbonded elements. A temperature traverse along the length of a fuel channel is shown in Figure 5.

The quantity of normal uranium required for critical loading was almost exactly 30 tons. The present loading is 54 tons to provide sufficient excess reactivity for the benefit of experiment and radioisotope target materials in the reactor as well as to provide for the poisoning effect of the Al-Si bonding material in the present elements. See Figures 7 and 8.

The reactor is operated on a round-the-clock basis with the only routine shutdown being from 5:00 a.m. to about 3:30 p.m. each Monday. The continuous operation is necessary for the varied experiments being conducted as well as for a routine production of radioisotopes. The percentage operating time since the reactor first attained critical loading is in excess of 90%. During the routine shutdown, each fuel

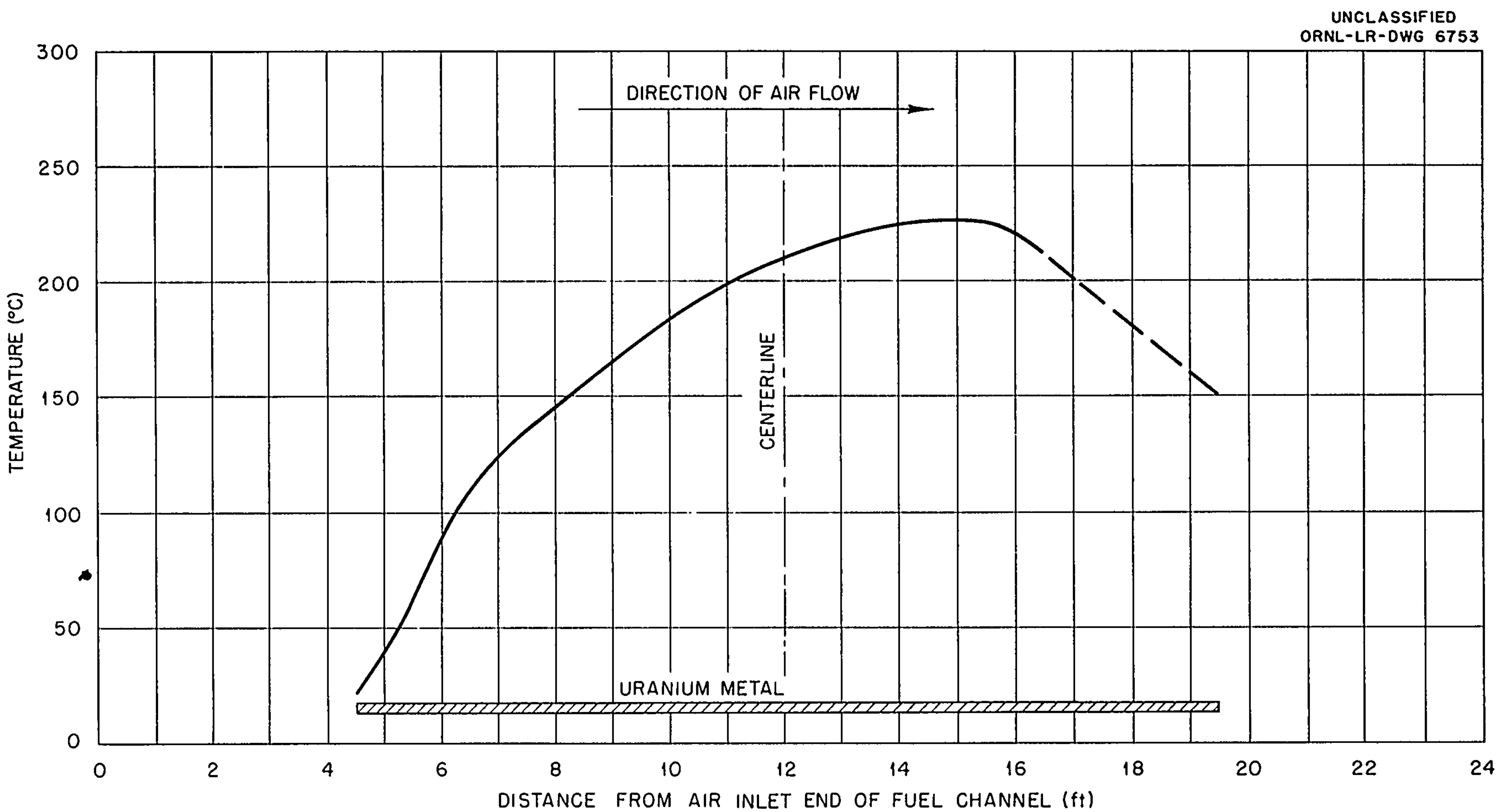

Fig. 6. Temperature Traverse Through a Fuel Channel Showing that the Peak Temperature is Downstream from the Reactor Center.

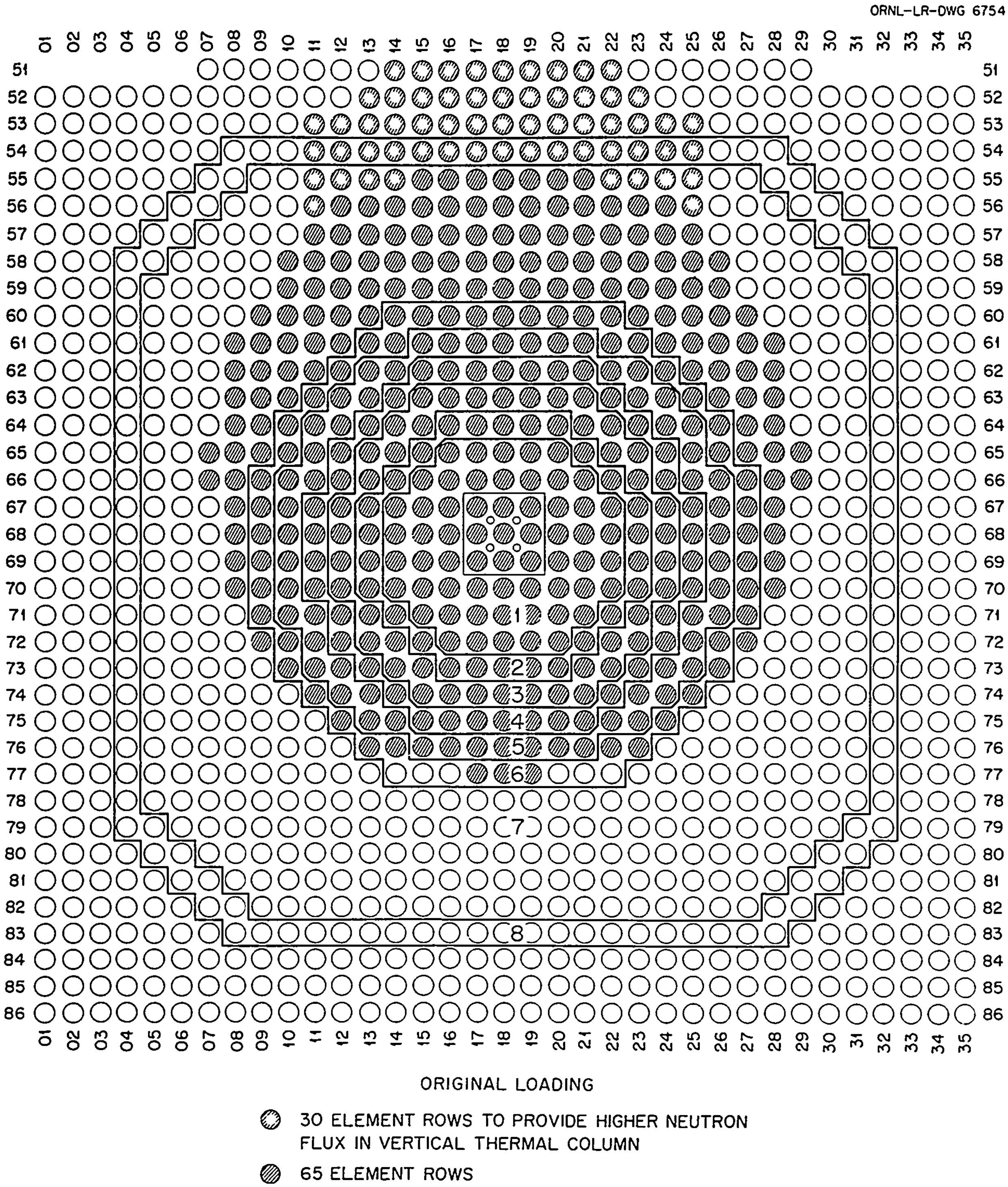

Fig. 7. First Operating Fuel Loading of 35.7 tons of Normal Uranium. The 30-Element Rows at the Top Were to Provide a Higher Neutron Flux in the Vertical Thermal Column.

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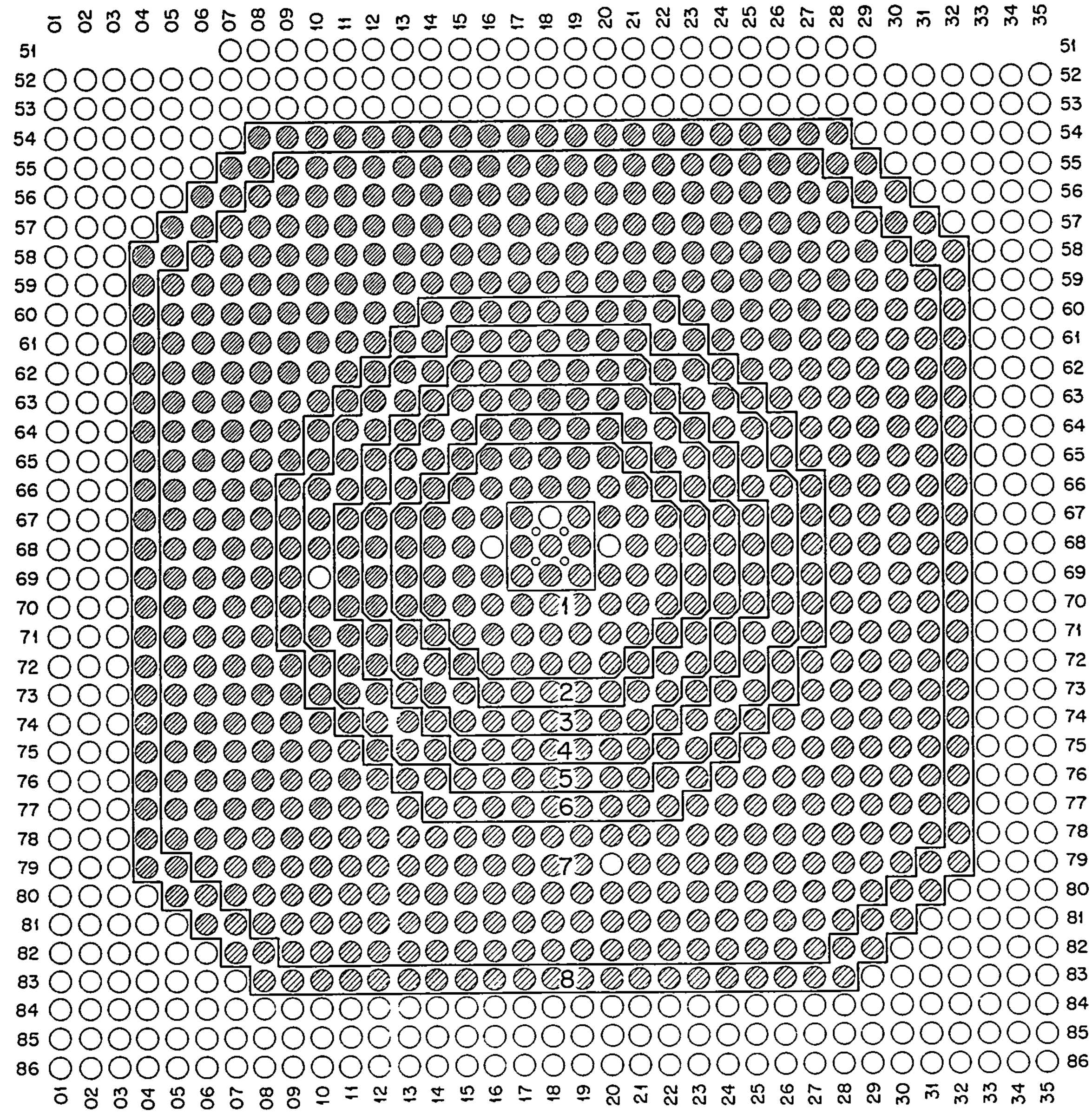

ZONE	NUMBER CHANNELS	NUMBER SLUGS
1	60	41
2	26	45
3	42	51
4	38	51
5	58	54
6	54	54
7	438	54
8	114	47

Fig. 8. The Present Fuel Loading Pattern of the Graphite Reactor Showing a Much Expanded Core Size and Shorter Rows at the Center to Depress the Temperature in that Region. This Loading Consists of 54.1 tons of Normal Uranium.

channel is inspected for any evidence of failure, changes in research equipment made, radioisotope targets are removed and inserted, and required maintenance performed. Close scheduling is required to accomplish this work in the allotted time and planning always starts each Thursday for the following Monday.

Other shutdowns are scheduled as required for emergency maintenance, of course, and shutdowns for special research or radioisotope production work are sometimes arranged with the permission of other research personnel using the reactor.

At the standard operating power level of 3.5 megawatts the maximum thermal neutron flux is 1.1×10^{12} n/cm^2 sec. Up until 1952 the power level was generally kept as high as possible without exceeding the temperature limitation of the fuel jackets. This caused several different power levels to be existing even during the course of one day ranging from 3.4 to 4.2 megawatts and caused a lot of extra work for the research personnel in normalizing their data. This was a case of doing something just because it had always been done and was a hangover from the old plutonium production days when it was required to operate at the highest power level possible. The present operation at a standard power level has somewhat simplified the work of the research personnel but even now very precise work has to be specially monitored at the exact facility being used.

Due to the size of the reactor and the placement of the regulating rods slow fluctuations of greater than one percent can take place in one day in any one location without any change in the over all power output of the reactor. As the temperature of the coolant (atmospheric air) increases from shortly after daylight until about 2:30 or 3:00 p.m., when the peak temperature usually occurs, the regulating rods move outward to compensate for the overall temperature rise in the reactor. This causes the peak flux in the reactor to move toward the center of the reactor in the direction the rods are traveling. The opposite effect begins shortly thereafter until about 10:00 p.m. after which nearly a stationary flux pattern exists until daylight. For this reason, research personnel needing precise neutron flux control prefer data taken at night unless they have automatic compensation in their equipment which many have at present.

Also, due to having two general purpose pneumatic exposure tubes and a vertical hole through which relatively large samples (up to 18" long by 2½" in diameter) can be inserted and removed without shutting down, many brief flux fluctuations occur all during the day as these facilities are used. Announcements five minutes prior to such fluctuations by way of a public address system gives each research man time to prepare for them or raise objections to their being done. Another such fluctuation occurs during a major regulating rod adjustment which must be made at any time the two regulating rods become unbalanced as much as 10 inches. This occurs due to having fine control movement on only

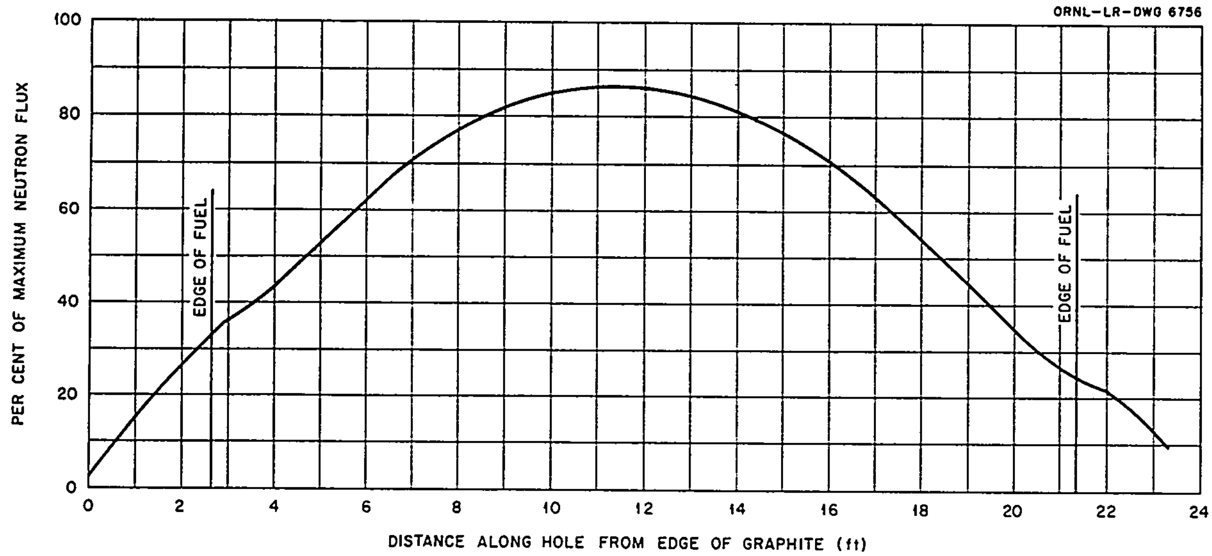

Fig. 9. A Typical Thermal Neutron Traverse Through One of the 4-in Square Experiment Holes.

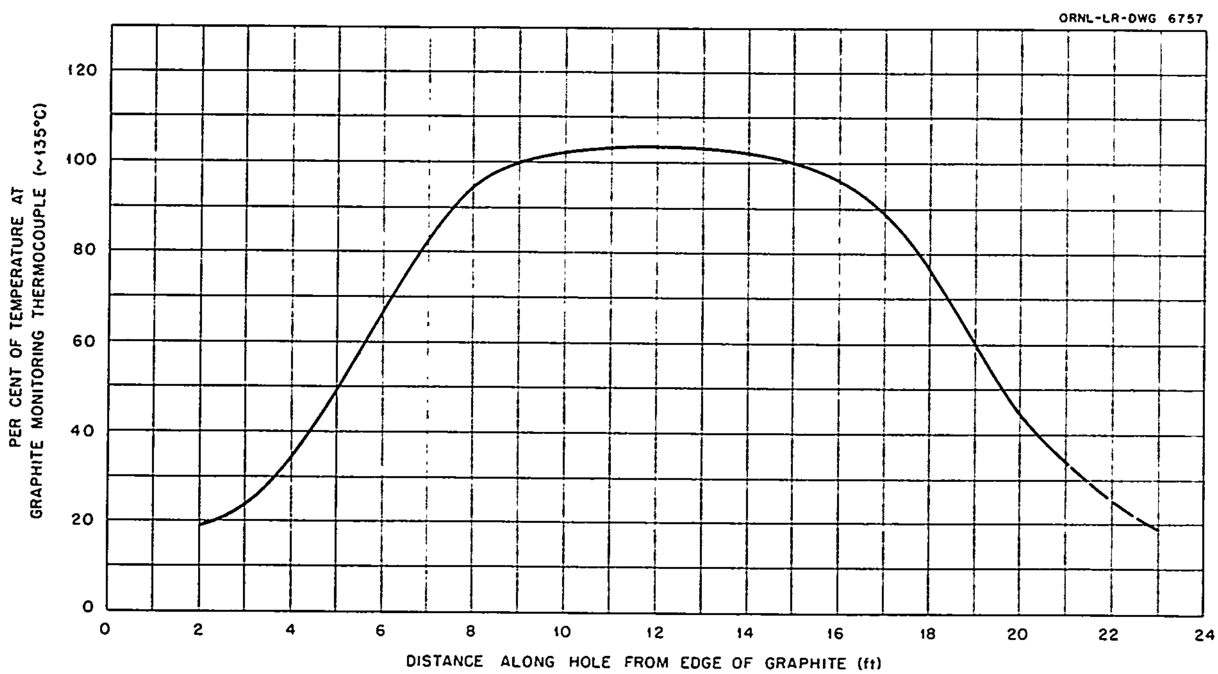

Fig. 10. A Typical Temperature Traverse Through a 4-in Square Hole Showing a Flattening at the Center.

one rod. When this rod has been moved inward or outward 10 inches farther than the one-speed rod, they are re-balanced by moving one in one direction and the other in the other direction simultaneously. At best, some fluctuation occurs and this, too, is announced five minutes ahead of time. The balancing procedure minimizes distortion of the flux pattern in the reactor. This technique need only be used during manual operation. While the reactor is in automatic control, the rods can be adjusted to be an even distance out at all times.

Since the total poisoning value of the five shutdown rods is only 2.7% $\frac{\Delta k}{k}$ the loading is limited to half this value for the cold reactor. Due to the low power density, roughly 600 watts per cubic foot, the xenon-135 poisoning is not severe only 0.2% $\frac{\Delta k}{k}$. The combined temperature coefficients amount to 0.4% $\frac{\Delta k}{k}$, making a total of 0.6% $\frac{\Delta k}{k}$. An allowance of about 0.3% $\frac{\Delta k}{k}$ is cancelled by the regulating rods to provide flexibility of control and for experiments of a temporary nature. Another 0.5% $\frac{\Delta k}{k}$ is used by permanently installed experiment facilities giving a total of approximately 1.4% $\frac{\Delta k}{k}$ excess reactivity for the clean cold reactor. The only possibility of prompt critical occurring is during startup and this is prevented by a careful slow startup procedure which requires fifteen minutes.

TABLE IV

SUMMARY OF GRAPHITE REACTOR INFORMATION

Size of graphite	24' x 24' x 24'-4" high
Thickness of concrete shield	7'0"
No. of fuel channels	1248
No. of 1.6" diameter holes through central part of core	4
Type of fuel	normal uranium
Dimension of aluminum-clad fuel element (slug)	1.1" diameter by 4.1" long
Weight of uranium metal per slug	1170 grams
Thickness of aluminum cladding	.035"
Bonding material between Al and U	Al-Si eutectic
No. of fuel channels containing fuel	821

24-slug rows	10
41-slug rows	51
45-slug rows	23
47-slug rows	115
51-slug rows	79
54-slug rows	543

TABLE IV (CONT'D)

No. of 4" square openings	56
No. of horizontal through holes (4" sq.)	22
No. of horizontal half holes (4" sq.)	6
No. of vertical holes (4" sq.)	6
No. of 4" sq. horizontal through holes used for control and shutdown rods	4
No. of 4" sq. horizontal openings for experimental and target exposures	47
No. of 4" sq. vertical holes for shutdown rods	3
No. of 4" sq. vertical holes for experiments and target exposures	3
Other experiment facilities	14
Total reactivity value of shutdown rods	2.7% $\frac{\Delta k}{k}$
Total reactivity value of control rods	1.1% $\frac{\Delta k}{k}$
Approximate amount of reactivity absorbed by experiments and radioisotope samples	0.5% $\frac{\Delta k}{k}$
Weight of uranium in reactor	54.11 tons
Maximum thermal neutron flux at 3.5 MW	1.1×10^{12}
Cadmium ratio	20
Average gamma photon energy	0.9 mev
Maximum gamma photon flux (at average energy of 0.9 mev)	5.13×10^{11} γ/cm^2-sec.
Maximum gamma dose rate	9.2×10^5 R/hr
Ratio of gamma flux to thermal neutron flux	0.50
Standard reactor power level	3.5 megawatts
Average graphite temperature at center of reactor	$\sim 135^\circ$C

TABLE IV (CONT'D)

Average metal temperature at hottest region	$\sim 270^{\circ}$C
Average neutron flux (based upon power level and amount of fuel)	5.0×10^{11} n/cm^2-sec
Ratio of maximum thermal neutron flux to average thermal neutron flux	2.24
Volume of active portion of reactor	5,933.4 cu.ft.
Power density inside active portion	587.5 watts/cu. ft.
Volume of coolant air	120,000 cfm.
Negative pressure inside reactor	$\sim$29" wg.
Operating metal temperature coefficient	$-$.29 inhour/$^{\circ}$C
Operating graphite temperature coefficient	$-$.77 inhour/$^{\circ}$C
Barometric pressure coefficient	$-$.38 inhour/mm Hg
Xenon poisoning coefficient	$-$25 inhours/1000 KW

SPECIAL RESEARCH EQUIPMENT AT THE GRAPHITE REACTOR

1. Neutron Spectrometers (See Figures 11 and 12.)

Three neutron spectrometers are in use. Two are operated by the Physics Division and one by the Chemistry Division. The primary beams of neutrons from collimators set in 4-inch square openings range from about ½ inch square to an inch square. This beam consists of neutrons of all energies from about 0.03 ev to more than 10 mev and cannot be used. From this beam a crystal set in its path scatters the neutrons at angles inversely proportional to their energy. By using a second collimator, neutrons of about 0.07 ev (about 1A$^{\circ}$ wave length) are obtained. These are used in much the same way as x-rays in studying crystal structures, crystal transitions at different temperatures (using heaters or refrigerants), and the location of nuclei in crystals. Neutrons are particularly useful in studying crystals containing hydrogen, deuterium, or tritium since they are scattered by nuclei rather than by shell electrons.

2. Vertical Low Temperature Exposure Facility - Hole 12

Operated by -- Solid State Division
Thermal neutron flux -- 8×10^{11} n/cm^2 sec.
Gamma -- 6.7×10^5 R/hr.

PHOTO 5991

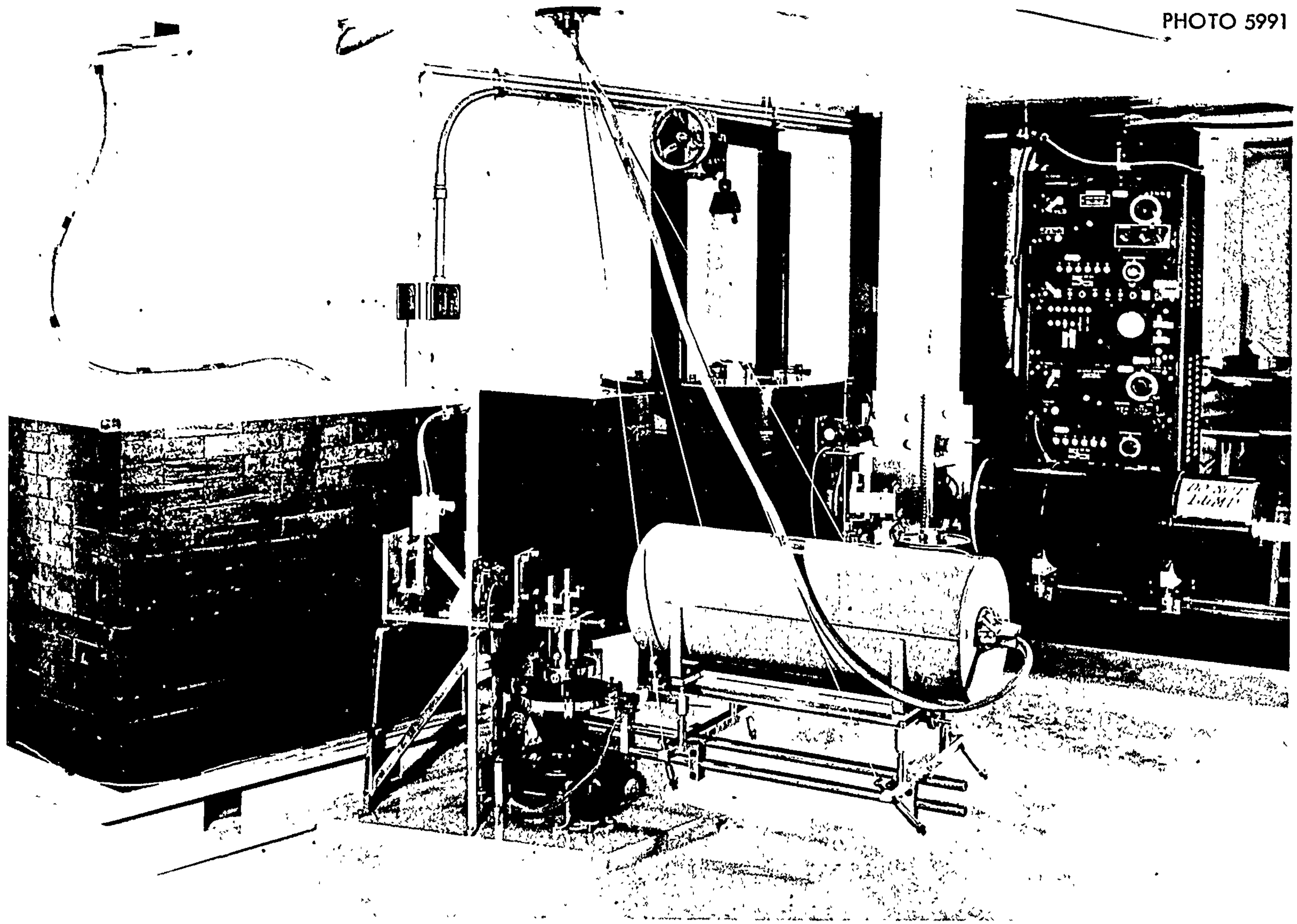

Fig. 11. A View of two Neutron Spectrometers Showing the External Shielding Required to Keep the Background Neutron Count Low.

DWG. 19795

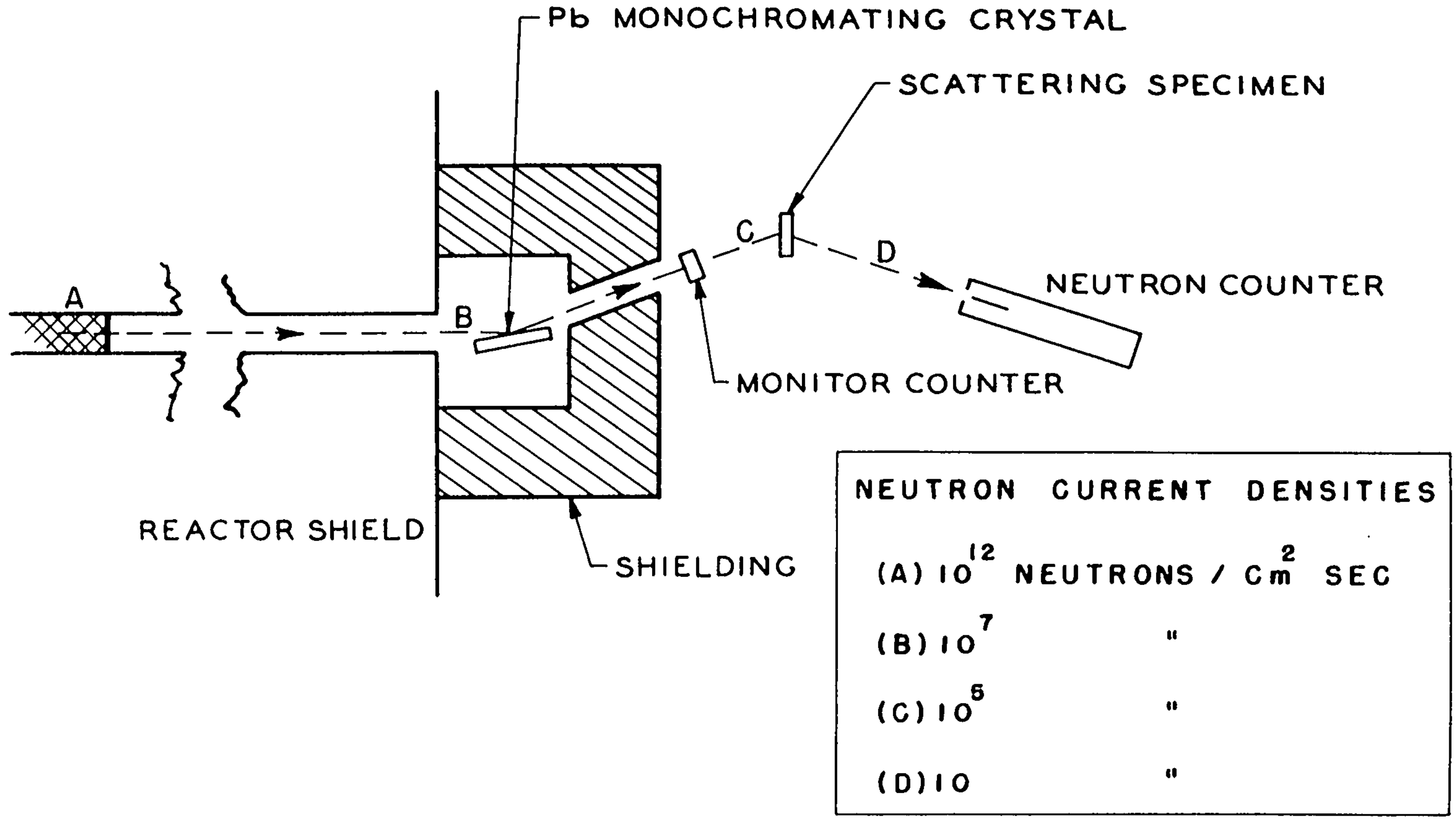

Fig. 12. A Schematic Sketch of a Neutron Spectrometer with the Parts Named.

This is a newly installed facility that is cooled by a helium refrigerator. The lowest temperature that can be obtained in the exposure chamber is about 18°K. The maximum sample size that can be accommodated is 1 inch in diameter by 24 inches in length. It will be used to study radiation damage without annealing occurring.

3. <u>Horizontal Low Temperature Facility</u> -- Hole 52-N

Operated by --- Solid State Division
Thermal neutron flux -- 3.6×10^{11} n/cm^{2}sec.
Gamma -- 3×10^5 R/hr.

The horizontal low temperature facility has been in operation since 1952. The exposure chamber can be cooled to 115°K by a stream of helium gas passing through a liquid nitrogen heat exchanger. The maximum size of samples is 7/8 inch diameter by 5 inches in length.

4. <u>Water-cooled Fast Neutron Exposure Facility</u> -- Hole 51-North

Operated by -- Solid State Division
Neutron fluxes:
Thermal -- 5.5×10^{11} n/cm^2-sec.
Fast -- 8×10^{11} n/cm^2-sec.
Gamma -- 5×10^5 R/hr.
Temperature in exposure chamber -- $\sim$25°C

The fast neutron source is a water-cooled hollow cylinder made of aluminum-clad, enriched uranium-aluminum alloy. The maximum sample size is $1\frac{1}{2}$ inch diameter by 11 inches long. Samples are inserted and removed by a chain conveyor.

5. <u>Water-cooled Horizontal Exposure Facility</u> -- Hole 19

Operated by -- Solid State Division
Thermal neutron flux -- 8.5×10^{11} n/cm^2-sec.
Gamma -- 7×10^5 R/hr
Temperature in exposure chamber -- $\sim$30°C
Maximum sample size -- $1\frac{1}{4}$ inch diameter x 8 inches long
Samples are inserted and removed by water pressure and are cooled by water flow.

6. <u>Vertical Water-cooled Facility</u> -- Hole 10

Operated by -- Reactor Operations Department for general usage by all research divisions and radioisotope production.
Thermal neutron flux -- 7×10^{11} n/cm^2-sec.
Gamma -- 5.7×10^5 R/hr
Temperature in exposure chamber -- 30°C (controlled)
Maximum sample size -- $2\frac{1}{2}$ inch diameter x 1 foot long

Samples for short exposure are tied onto waxed linen cords. Long exposures are done in aluminum cans with upright bails which are lowered to the bottom and retrieved with grappling hooks. Reactor shutdown is not required for insertion or removal. Samples are stored in six-place rotating magazine shield over hole.

7. Fast Pneumatic Tube -- Hole 56-north (See Figure 13.)

Operated by -- Physics Division
Thermal neutron flux -- 3.6×10^{11} n/cm^2 sec.
Gamma -- 3×10^5 R/hr.
Temperature of exposure chamber -- $\sim 50^\circ$C
Maximum sample size -- 5/16 inch thick by 13/16 inch wide by 1 1/4 inch long

Samples are inserted into and removed from the reactor by CO_2 pressure. Exposure time can be less than one second. Removal time is less than one second. Equipment operates automatically, exposure being controlled by timing mechanism.

8. General Usage Pneumatic Tubes -- Hole 22-South

Operated by -- Reactor Operations Division for use by all research divisions and for radioisotope production.
Thermal neutron flux -- 6.5×10^{11} n/cm^2 sec.
Gamma -- $\sim 5 \times 10^5$ R/hr.
Temperature of exposure chamber -- $\sim 80^\circ$C
Maximum sample size:
Large tube -- 3/4 inch diameter x 2 1/4 inch long.
Small tube -- 7/16 inch diameter x 2 inches long.

Ordinarily samples are discharged to a storage shield to await pickup. Samples from the large tube can also be made to travel through a shielded tube to a laboratory room for quick analyses. Samples are inserted into and removed from the reactor by CO_2 pressure.

9. Fuel Channel Pneumatic Tube -- Channel 2079

Operated by -- Reactor Operations Department for usage by all research divisions and for radioisotope production.
Thermal neutron flux -- 5.5×10^{11} n/cm^2 sec.
Gamma -- $\sim 4.5 \times 10^5$ R/hr.
Temperature of exposure chamber -- $\sim 50^\circ$C
Maximum sample size -- 7/8 inch diameter x 3 3/8 inches long.

This tube utilizes one of the two fuel channels that were made unusable for fuel by removal of a multiple fuel rupture. Access is through a hole drilled through the concrete shield opposite the charging face. Samples are inserted and removed by CO_2 pressure and stored in a eight place magazine shield.

Fig. 13. The External Parts of the Fast Pneumatic Tube.

10. Oscillator -- Hole 56-South (See Figure 14.)

Operated by -- Physics Division

This facility is a four-inch square hole which contains a boron-coated ionization chamber beside which a small beryllium oxide boat containing a specimen can be oscillated. The current through the ionization chamber will be inversely proportional to the neutron absorption of the specimen. By oscillating the specimen, a wave-form voltage change will be introduced in the circuit whose amplitude will be proportional to the neutron absorption cross section. By using some material whose cross section is well known, such as gold, for a standard, the neutron absorption cross section of any material may be determined.

11. Stringer Holes --Hole 13 and Hole 14 (See Figure 15.)

Operated by -- Reactor Operations Department for use by all research divisions and for radioisotope production.
Thermal neutron flux -- 1×10^{11} to 9×10^{11} n/cm^2 sec.
Gamma -- 10^4 to 8×10^5 R/hr.
Temperature in exposure regions -- $\sim 35^\circ$C to $\sim 160^\circ$C
Maximum sample size -- 3/4 inch diameter by 3 inches long.

These facilities are stringers or trains of connected 4-foot long graphite trays that extend all the way through two 4-inch-square horizontal holes. Each tray accommodates 36 targets and the two holes accommodate a total of 389 targets. Reactor shutdown is required for removal or insertion of materials, so the minimum exposure time is one week.

12. "Doughnut" Holes -- Fuel channels 1768, 1867, and 1968 (See Figure 16)

Operated by -- Either the research divisions or by the Reactor Operations Department depending upon the material inserted.
Neutron fluxes:
Thermal -- 4×10^{11} n/cm^2-sec.
Fast -- 2.2×10^{11} n/cm^2-sec, > 0.5 mev.
Temperature in exposure chamber -- $\sim 40^\circ$C
Maximum sample size -- 1/2 inch diameter x 11 inches long.

These are fuel channels in the center of the core region which each contain seven 4-inch long hollow aluminum-clad normal uranium cylinders. Targets are tied to either iron or aluminum wires of measured length to center them in the uranium. Removal is accomplished by winding the wire up on a shielded windlass. Reactor shutdown is required for removal or insertion.

Fig. 14. The Oscillator Used in Making Neutron Absorption Measurements. The Drive Mechanism Was Made from a Washing Machine.

PHOTO 11805

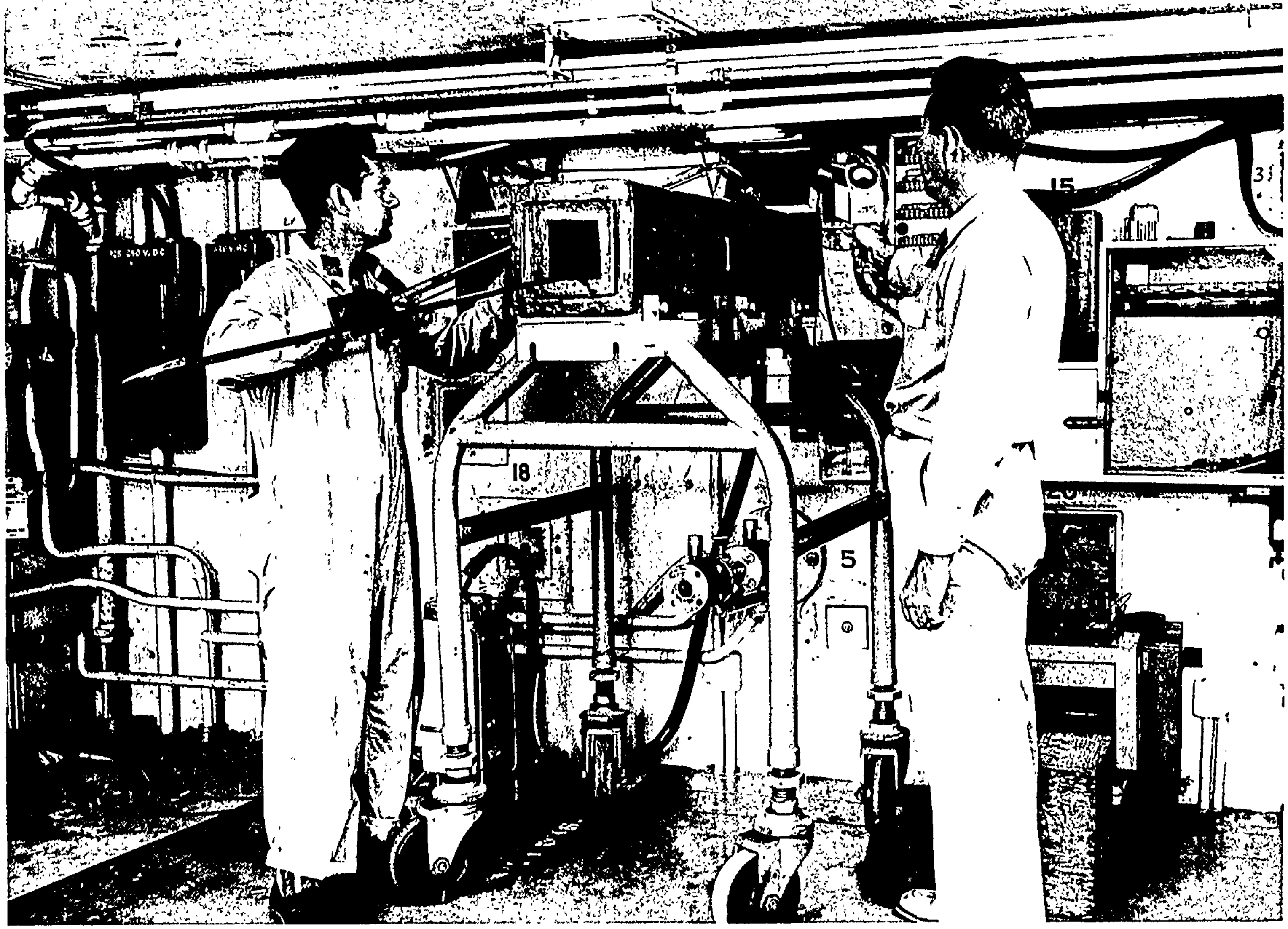

Fig. 15. A View of Operators Removing Radioisotope Targets from a "Stringer" Hole. Notice the Vacuum Cleaner which Removes Dust from the Graphite Tray as it Is Withdrawn from the Reactor through a Lead Shield.

PHOTO 9682

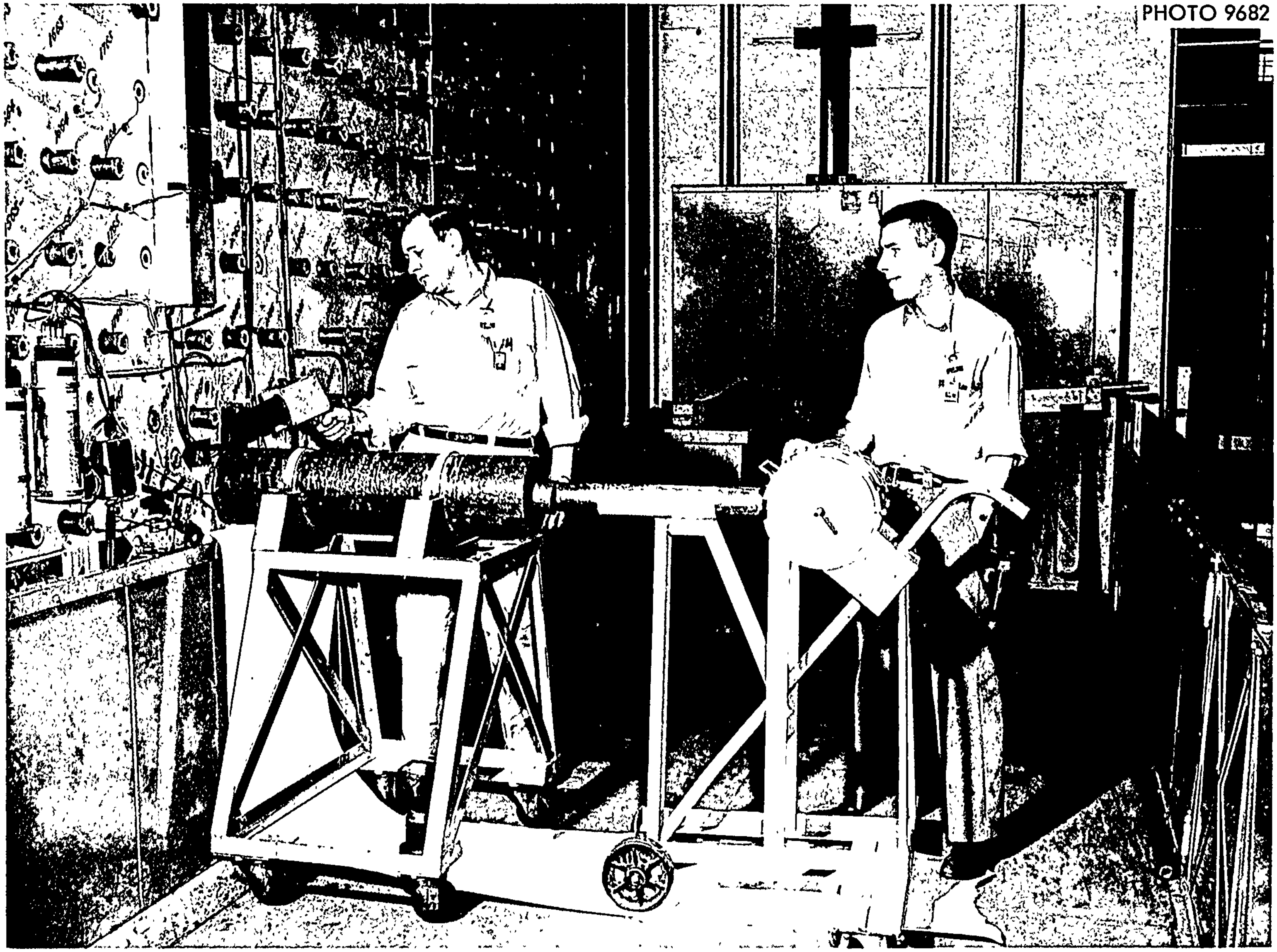

Fig. 16. Research Sample Being Removed from a Charging Face Hole. The Specimen Is Pulled into a Shield by an Attached Wire which Is Rolled up on a Lead-Shielded Windlass.

13. Vertical Thermal Column (See Figure 17.)

Operated by -- Primarily the Physics Division with minor use by other divisions.
Neutron Fluxes:
Thermal -- 7×10^7 n/cm^2-sec at top of column.
Fast -- negligible
In-Cd ratio --- $\sim 10^6$
Gamma -- $\sim$135 R/hr at top of column
Average gamma energy -- $\sim$3 mev.
Temperature -- Room temperature at top of column.

This thermal column is a stack of graphite blocks in a 5-foot square (at the bottom) hole through the roof of the reactor shield centered over the reactor core. The top is shielded by a 5-foot square tank of water with lead and cadmium around the sides. Materials to be irradiated or radiation shield configurations to be tested are lowered through the water to the bottom of the tank.

14. Horizontal Thermal Column -- opposite fuel charging side (See Figure 18.)

Operated by -- Physics Division
Neutron Fluxes:
Thermal -- 5×10^9 n/cm^2-sec.
Fast -- In-Cd ratio is 130
Gamma -- 1.2×10^4 R/hr
Temperature -- Room temperature

This thermal column opening is not used as a thermal column but as a lid tank for shielding tests. The opening through the reactor shield contains a 2-S aluminum tank which can be filled with water to act as a radiation shutter. A concrete-shielded water tank just outside the hole normally acts as the biological shield when the shutter tank is empty. Shielding configurations are built up in the outer tank and checked for attenuation efficiency.

15. Inclined Biological Tunnel (See Figure 17.)

Operated by -- Biology Division and Reactor Operations Department
Neutron Fluxes:
Thermal -- 1×10^9 n/cm^2-sec.
Fast -- negligible
In-Cd ratio -- 10^5
Gamma -- 360 R/hr
Temperature -- Room temperature
Maximum specimen size -- 7 inches x 3 inches x 3 inches

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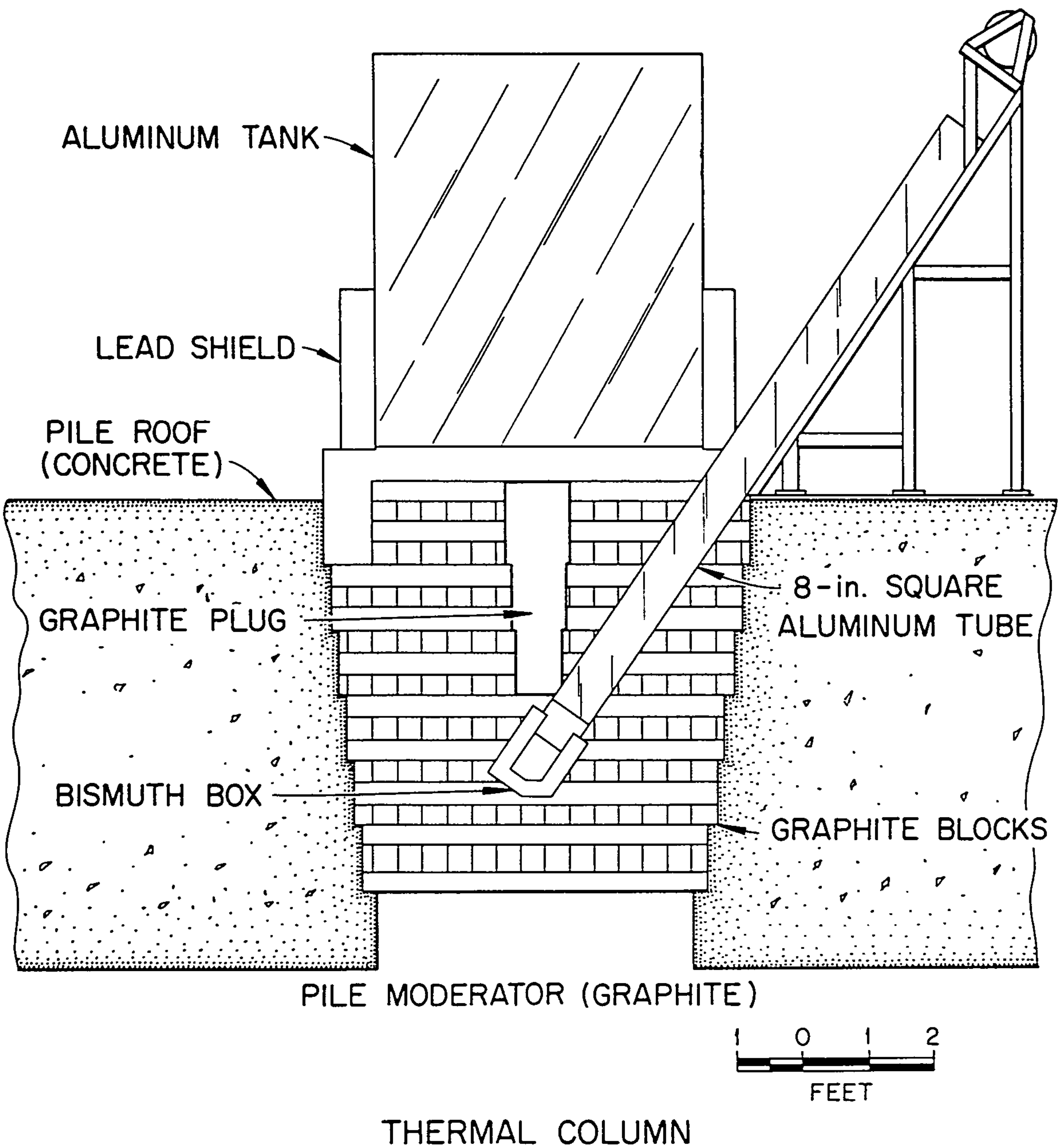

Fig. 17. A Sectional Sketch of the Vertical Thermal Column Showing the Inclined Biological Tunnel.

Fig. 18. Looking Down into the Lid Tank at the Horizontal Thermal Column Opening. An Enriched Uranium Source Plate Between the Tank Supplies Fast Neutrons and Shield Configurations to be Tested Are Assembled in the Outer Tank.

This biological tunnel was built in order to lower the gamma to neutron ratio for biological exposures beyond the value of the facilities built into the reactor shield. It is a slanted shield plug through the graphite in the thermal column and the exposure chamber is enclosed with a 4-inch thick layer of bismuth metal. Specimens are put into a graphite box which is affixed to the lower end of the tunnel. Movement of the plug is done by a hoist.

16. Lead-lined Biological Tunnel

Operated by -- Biology Division and Reactor Operations Department
Neutron Fluxes:
Thermal -- 1.3×10^9 n/cm^2-sec.
Fast -- Mn-Cd ratio is 70
Gamma -- 200 R/hr
Temperature -- $\sim 25^\circ$C
Maximum specimen size -- 24" long x 12" wide x 10" high.

This biological tunnel was built into the reactor shielding at the time of construction. It is located in the shield above the reactor so that neutrons and gamma radiation entering it come primarily through the bottom of the exposure chamber and are filtered through a 4-inch thick layer of lead. A ventilating system pulls fresh air from outside the reactor through the exposure chamber and into the reactor coolant stream. Specimens are rolled into the chamber on trays by means of push rods. A series of three lead gates, only one of which can be opened at a time, shield the operator. A concrete barricade outside the reactor shield provides further protection. Specimens can be inserted and removed while the reactor is operating.

17. Bare Biological Tunnel

Operated by -- Biology Division and Reactor Operations Department
Neutron Fluxes:
Thermal -- 5×10^8 n/cm^2-sec.
Fast -- Mn-Cd ratio is 73
Gamma -- $\sim$3400 R/hr

The bare biological tunnel was built into the reactor shielding at the time of construction. It is similar to the lead-lined tunnel in all aspects except for the lead lining. Since it is located farther from the vertical centerline of the reactor than the lead-lined tunnel, its neutron flux is lower.

18. Other more temporary equipment is built at the experiment openings as desired and frequent exposure of materials or equipment is made inside the 4-inch square holes and in uncharged fuel channels. Some examples are shown in Figures 19, 20, 21, and 22.

PHOTO 11933

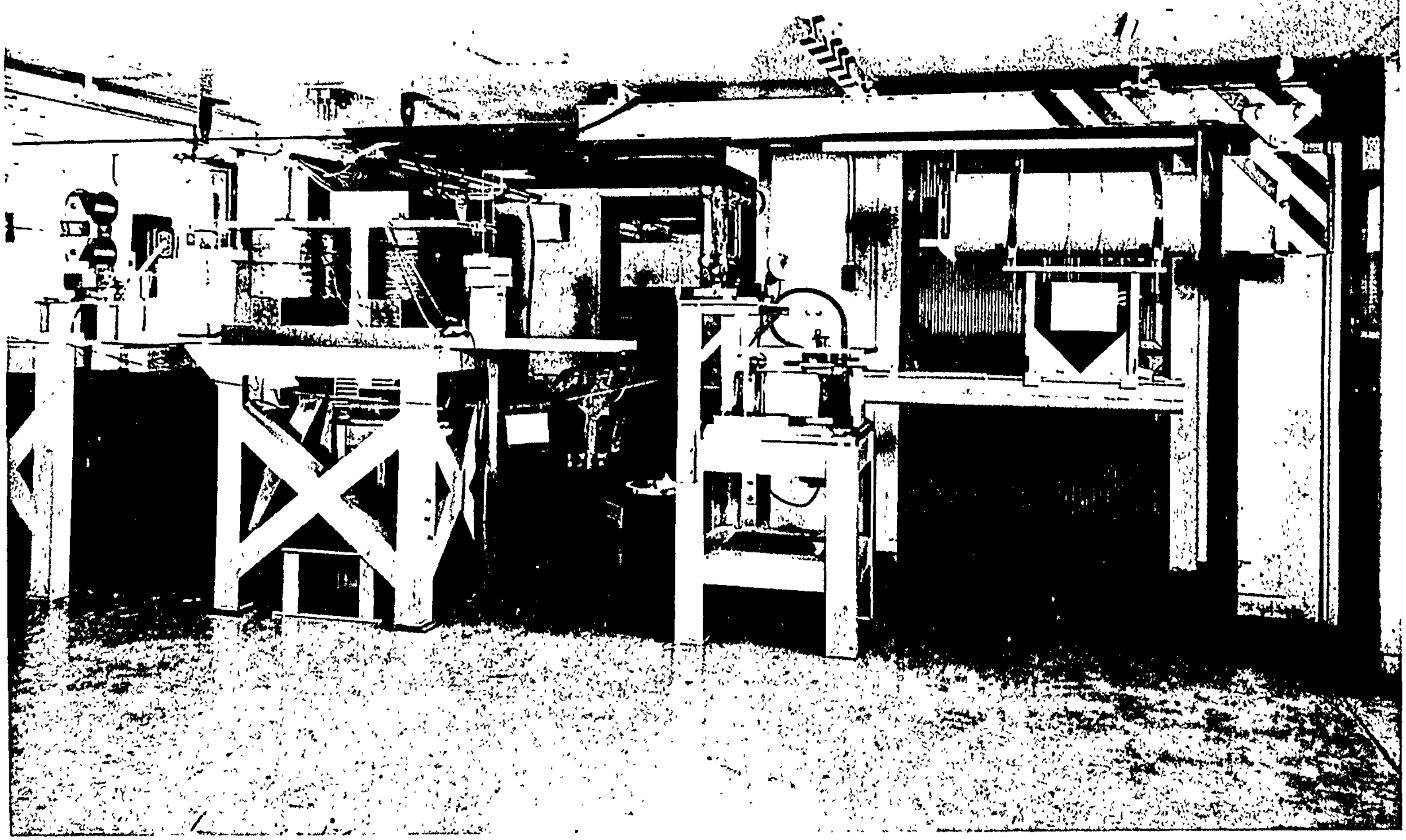

Fig. 19. Equipment at a Neutron Collimator for Performing a Stern-Gerlach Experiment with Neutrons.

PHOTO 9875

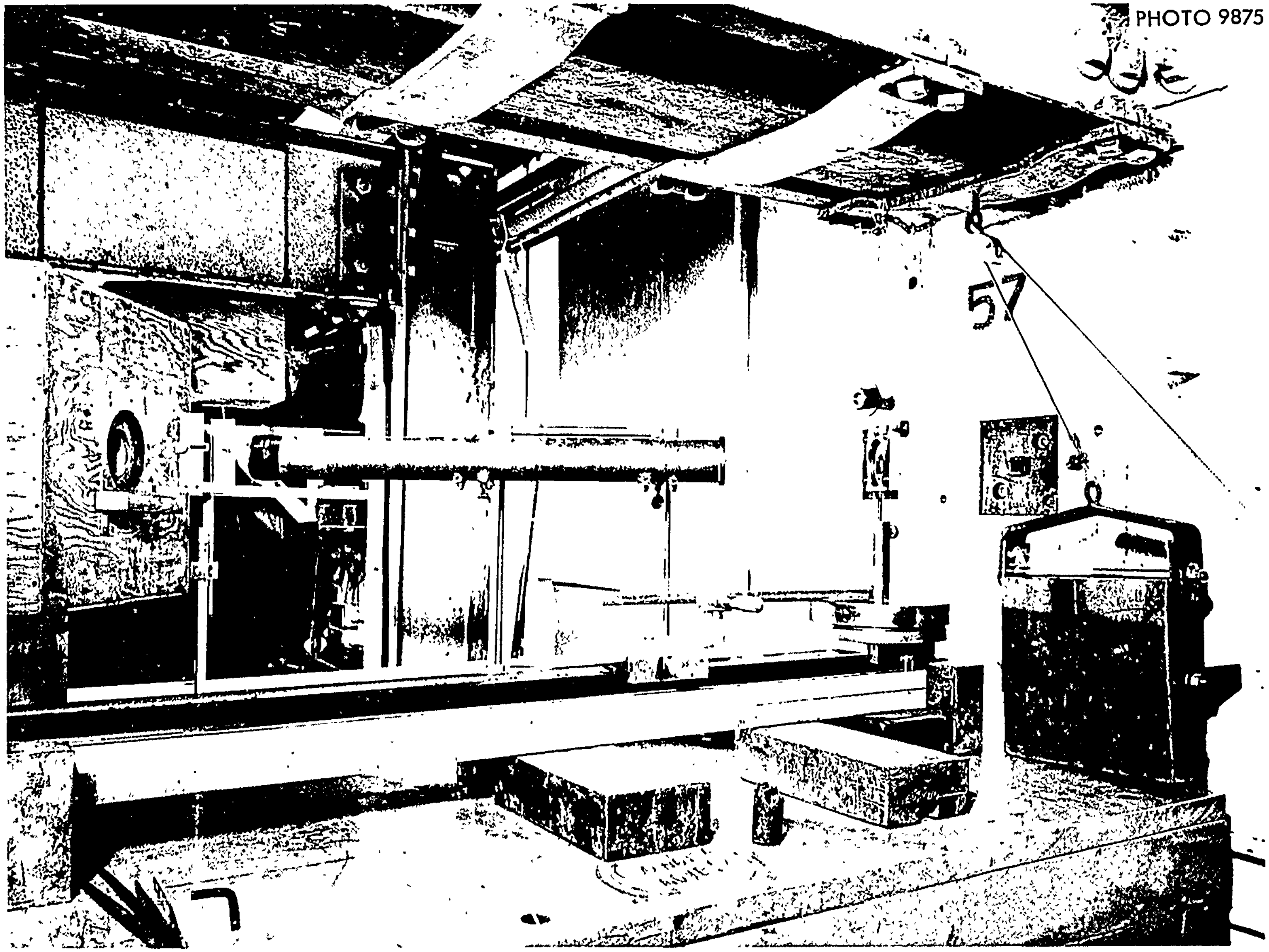

Fig. 20. Neutron Collimator Used by the Oak Ridge School of Reactor Technology (ORSORT) for Performing Short Experiments. The Setup Shown Is for an Experiment in the Diffraction of Neutrons with a Crystal.

LOW INTENSITY TESTING REACTOR

The Low Intensity Testing Reactor (LITR) is probably the only operating reactor that was built from left over test parts. Originally the tank that contains the reactor core was a mock-up assembly for measuring the water flow and mechanical characteristics of the Materials Testing Reactor (MTR) which is now operated at the Arco, Idaho, Reactor Test Station by the Phillips Petroleum Company for the AEC. (See Figure 23.) Since this installation was not intended to be permanent, all portions of the reactor tank except that surrounding the core were made of ordinary steel. The section containing the core is of 3-S aluminum since tests of actual flow through the coolant shells of actual beam hole thimbles had to be made. The hydraulic tests were completed in 1949 and a mockup of the beryllium reflector to be used in the MTR was built into one quadrant of the core tank with only a minimum thickness of beryllium surrounding the remainder of the core. With this assembly, a criticality test and neutron distribution measurement was made in 1950.

After these tests were completed, the need for a training reactor for the operating personnel of the MTR was recognized and conversion of the test mockup to a low power temporary reactor was completed on March 2, 1951. (See Figure 24.) The maximum power level was to be 500 kilowatts.

The conversion consisted of the following:

1. Painting the inside of the steel portions of the reactor tanks and some external piping to inhibit rusting.

2. Stacking a permanent beryllium reflector held in place by a sheet aluminum housing. (Figures 25 and 26).

3. Providing access holes for the various ionization chambers used for control. (Figure 27).

4. Adding an additional shim-safety rod to the two used for the criticality test.

5. Surrounding the reactor tank with a concrete block shield and extending the beam holes through the shield. Also providing shielding for the holes. (Figure 28).

6. Replacing the 20,000 gallon per minute water system with a smaller one to provide a flow up to 300 gallons per minute and providing a heat exchanger.

7. Enclosing two sides and the top of the reactor with rooms for shelter of experiments and operating personnel.

PHOTO 14151

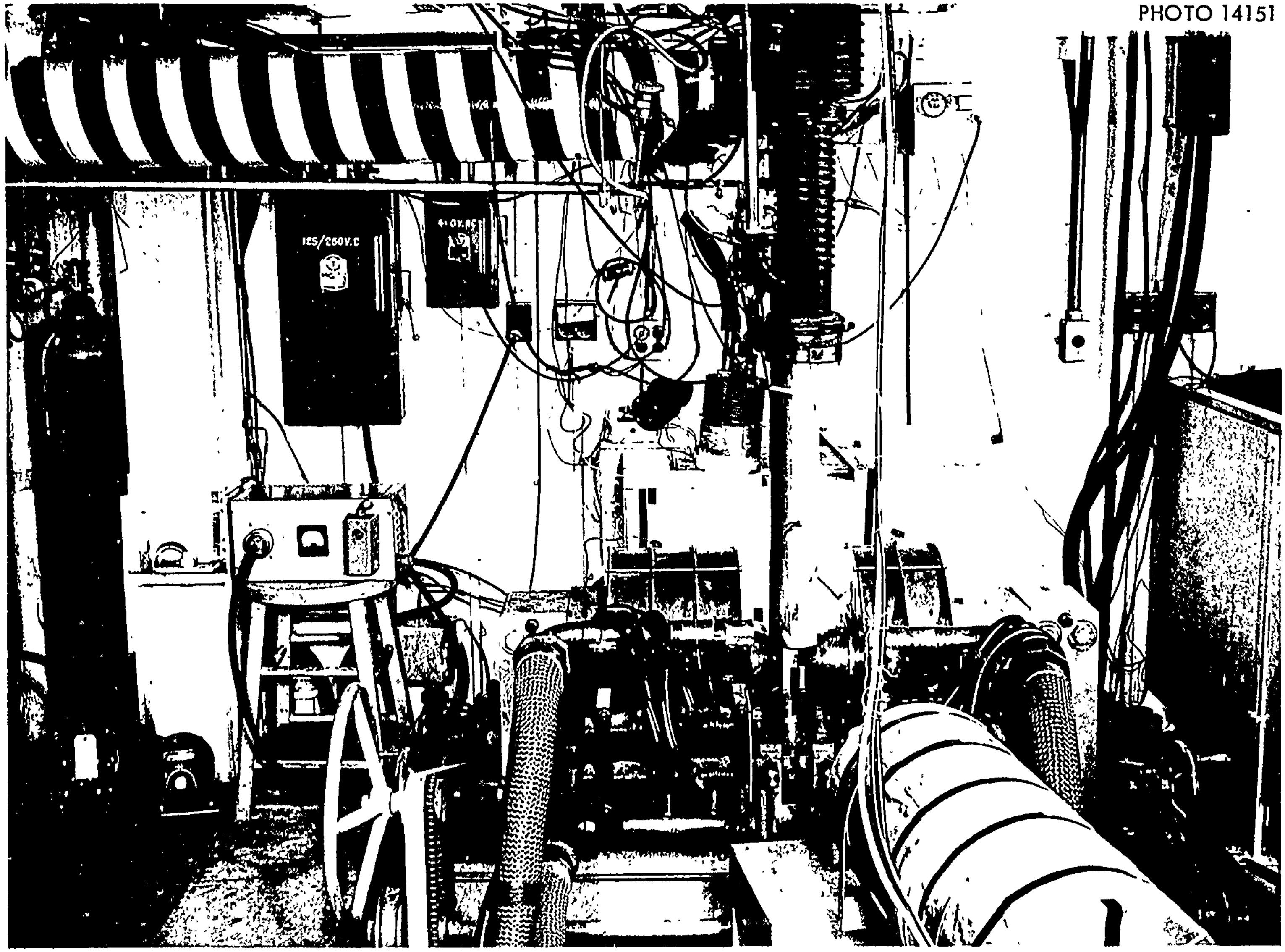

Fig. 21. The External-Field Polarization of In^{115} Nuclei. Neutrons from a Collimator Are Polarized by a Magnetic Field and Used to Measure the Degree of Polarization of the In^{115} Nuclei.

PHOTO 10948

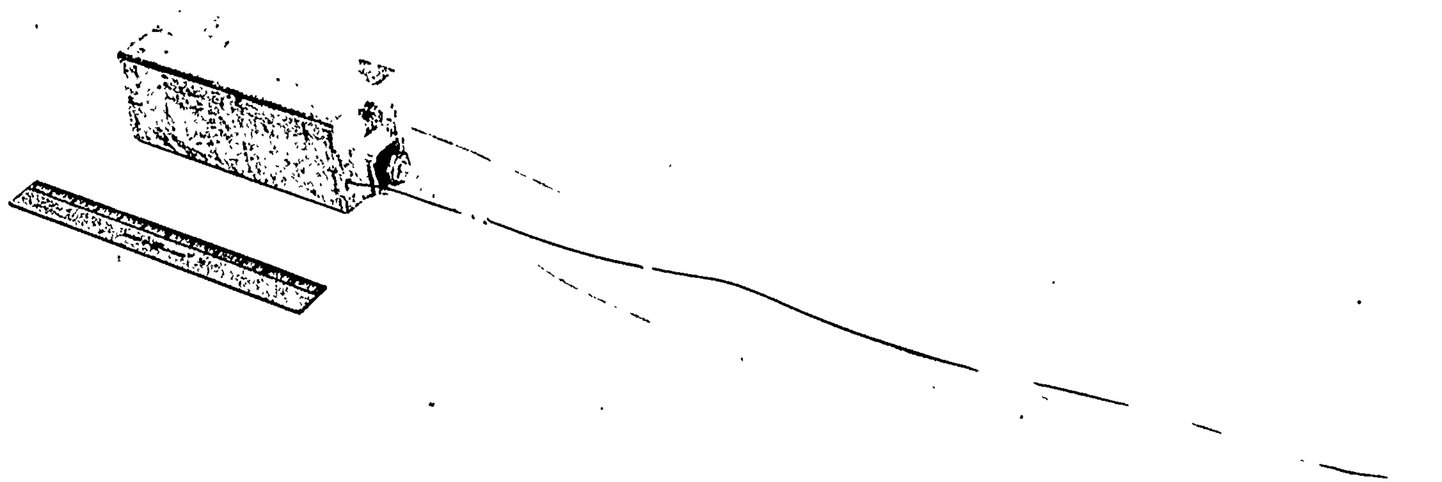

Fig. 22. A Typical Experiment Can Used in the 4-inch Square Holes. Lead Wires to Furnaces, and Thermocouples or Other Metering Devices Are Brought out of the Reactor through Serpentine Openings through the Shield Plugs.

Fig. 23. The Original Bare Mockup of the Materials Testing Reactor (MTR) which Was Later Converted to the Reactor Now Known as the Low Intensity Testing Reactor (LITR).

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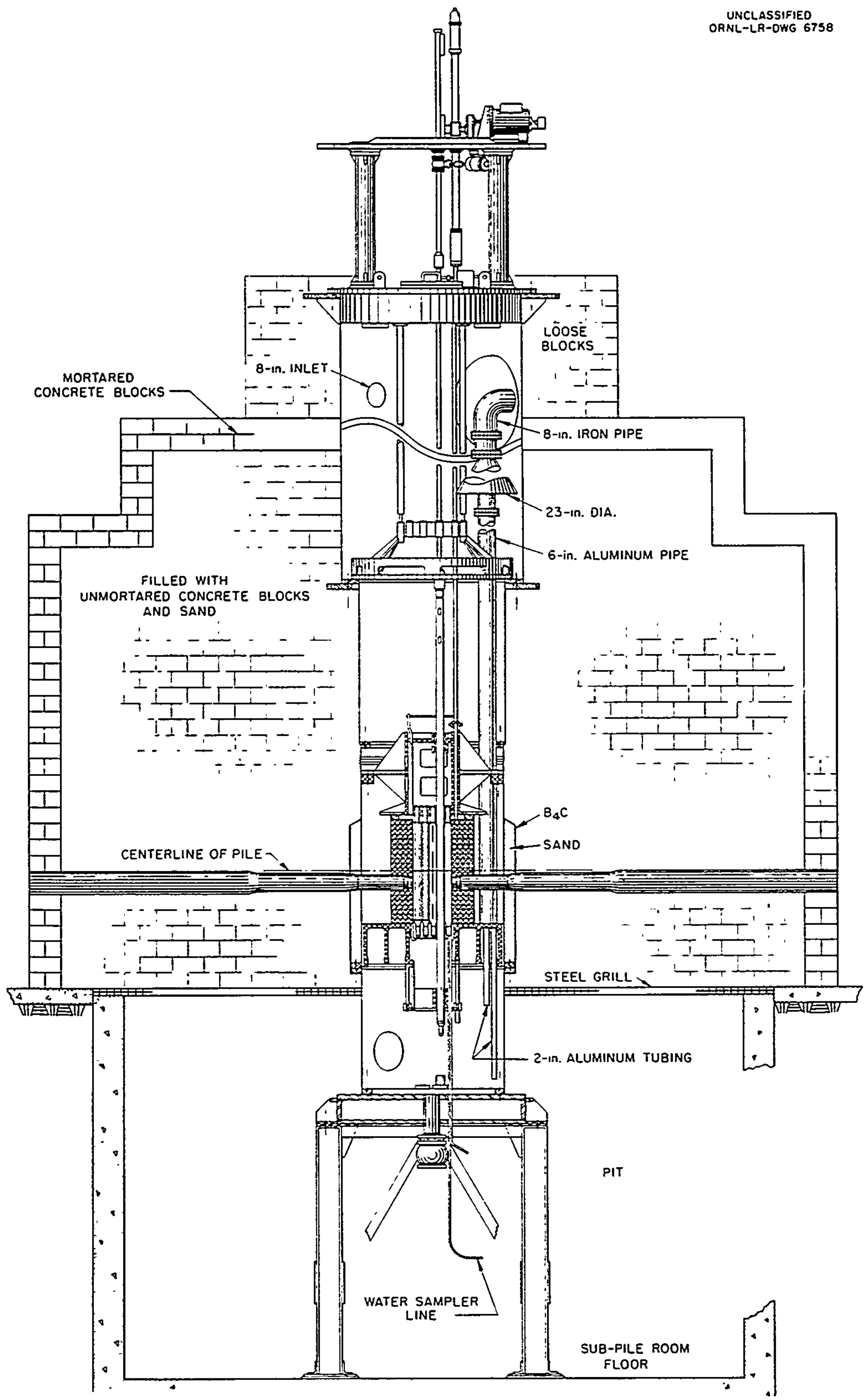

Fig. 24. Sectional Drawing of the LITR Showing the Reactor Tank, Core, Beam Holes, Shielding and Internal Water Lines.

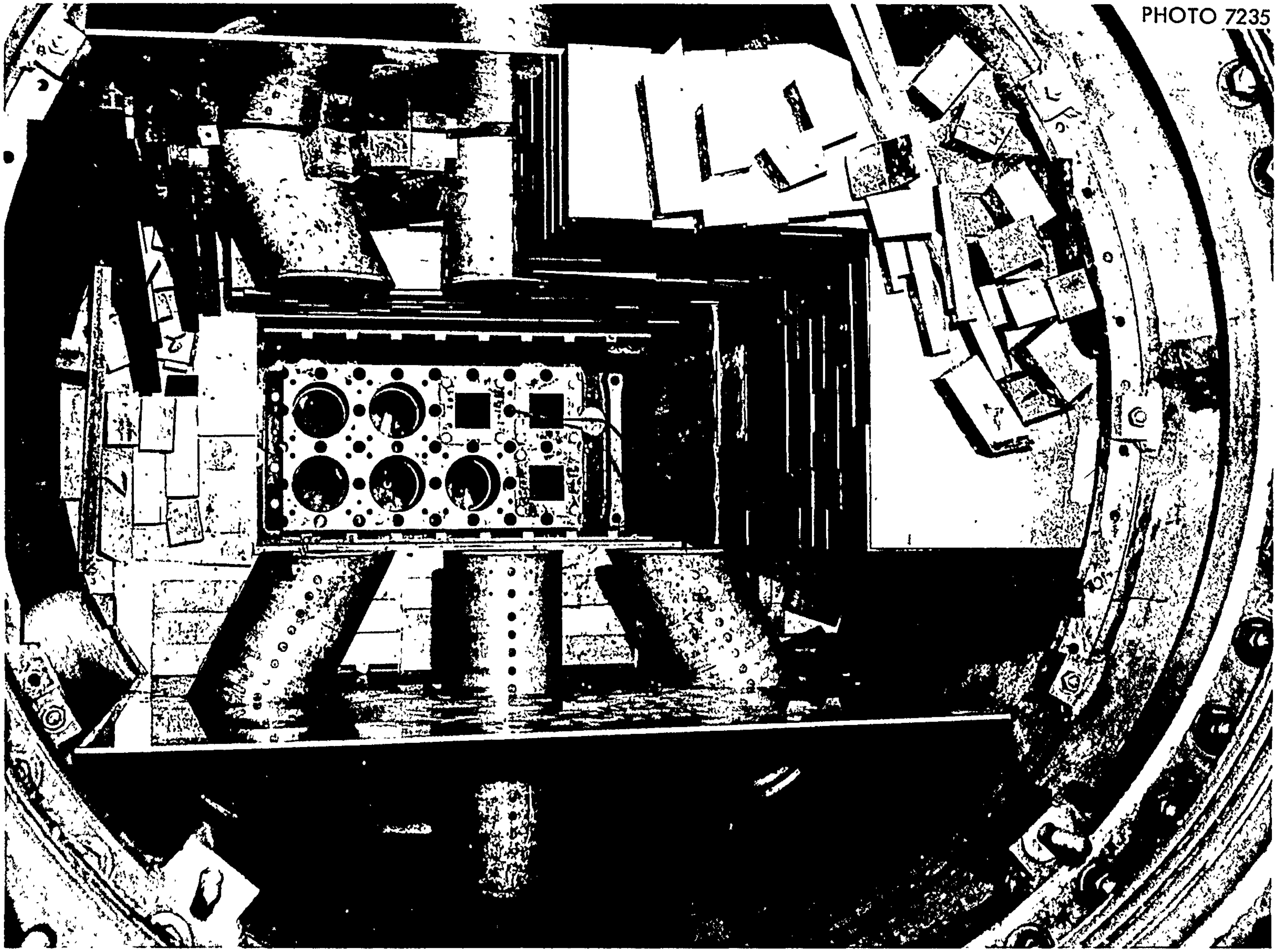

Fig. 25. A View of the LITR Core Space with the Permanent Beryllium Being Stacked Around the Beam Hole Thimbles.

PHOTO 7405

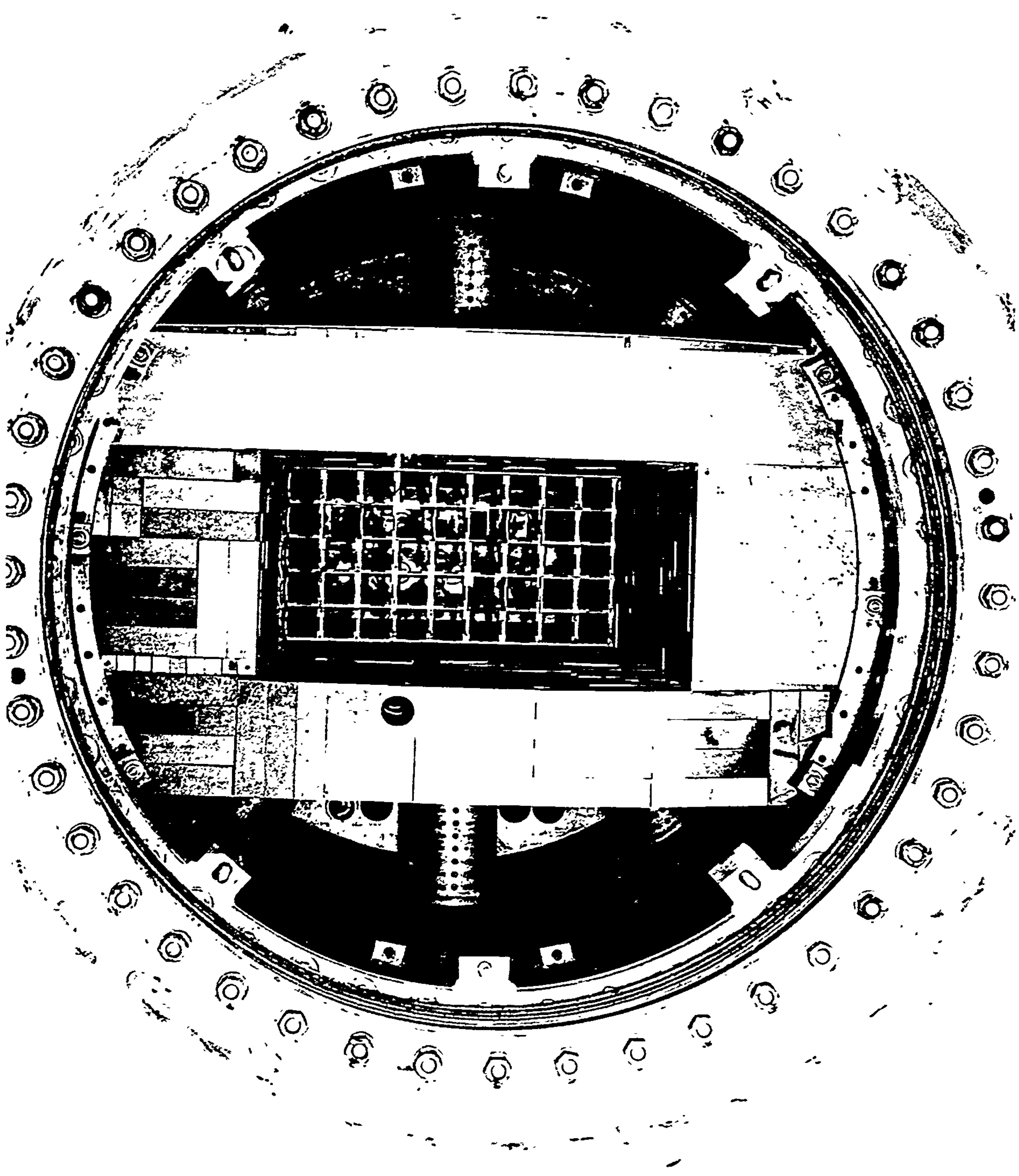

Fig. 26. A View of the LITR Core Space with the Stacked Beryllium in Place Prior to Being Covered with the Sheet Aluminum Housing.

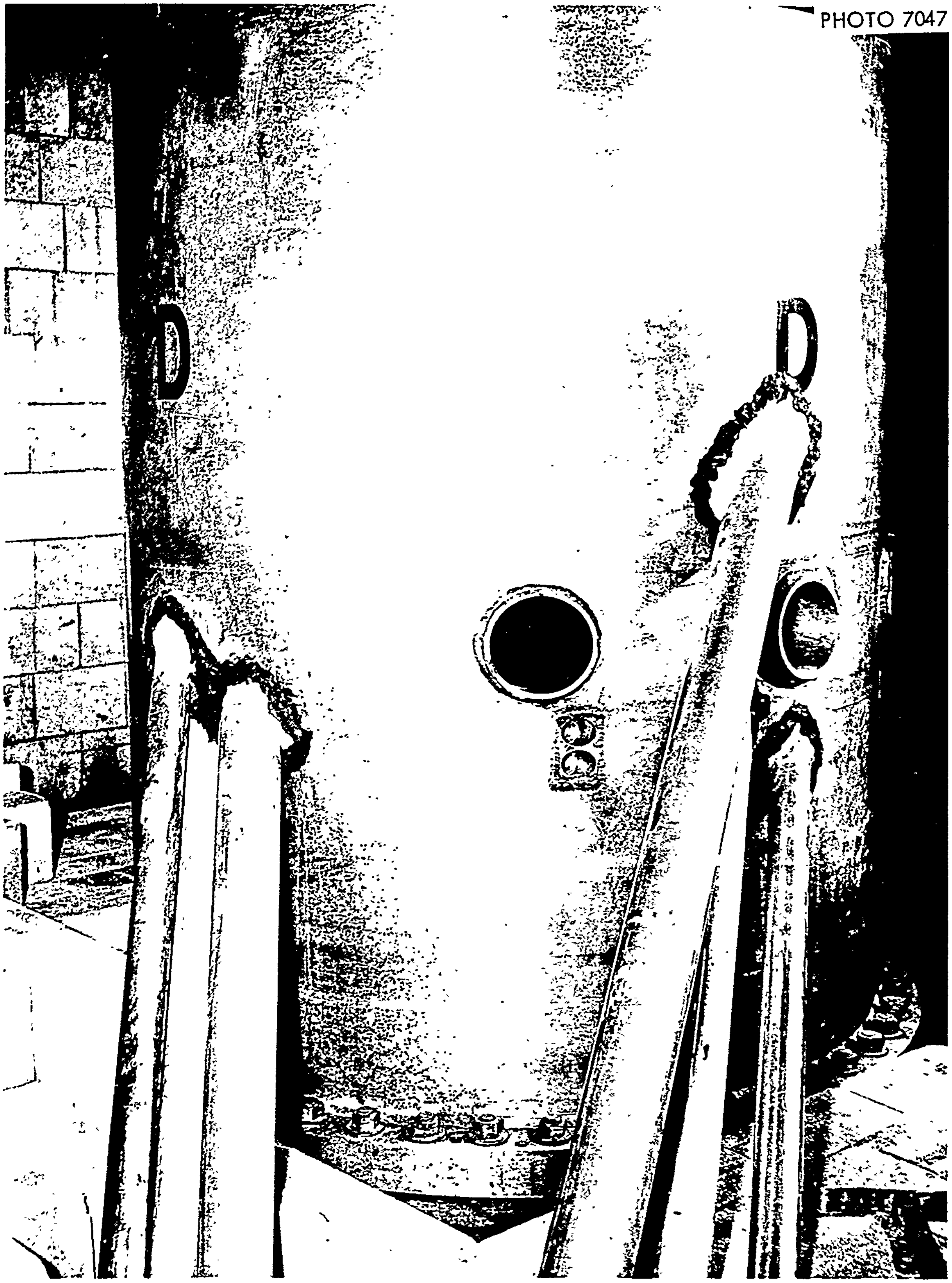

Fig. 27. The Ionization Chamber Access Tubes Before Being Covered with Shielding.

PHOTO 7237

Fig. 28. The Stacking of the Unmortared Concrete Block Shielding. The Large Pipes Are the Beam Hole Tubes.

8. Providing a special radioactive waste water disposal system including two retention ponds.

9. Permanentization of the reactor control room and the control instrumentation. (Figure 29).

During the time that the reactor was being used for training, it was seen that conversion to a research and radioisotope producing reactor would require only slight modification and would not be excessively expensive. This further modification included only increasing the cooling capacity and making the shield thicker. This was completed and operation at a power level of 1.5 megawatts began on April 25, 1952. This was raised to 3 megawatts on September 2, 1953, by further thickening the shielding on the exit water line from the reactor.

The LITR is a heterogeneous light water cooled, light water moderated, beryllium reflected enriched uranium reactor. The size of the core that contains the fuel plates is roughly 2 feet high by 9 inches wide by 2 feet long and contains about 3400 grams of U^{235}. The fuel assemblies are roughly 3-inch square pipes which contain sixteen 24 5/8 inch long plates each consisting of a layer of an aluminum and enriched uranium alloy sandwiched between layers of aluminum. Two walls of the pipe are also fuel plates making a total of eighteen plates per element. The total thickness of each plate is about 60 thousandths of an inch. They are separated about a tenth of an inch apart by spacers to allow passage of water for cooling. The water between the plates is also the neutron moderator. The plates are curved laterally on a 5.5 inch radius to strengthen them and to define the direction of thermal deformation.

The shim-safety rods are actually special fuel elements. Their total length is 13 feet 7 $\frac{1}{2}$ inches. The lower-most section is made of stainless steel to provide weight and to withstand the impact of hitting the shock absorber when the rod falls. The bottom end is cylindrical and acts as a piston in the water-filled shock absorber shell to lessen the force of impact upon the bottom of the tank. Above the stainless steel portion is an aluminum section containing fuel plates. The fuel plates are in the core when the rod is fully withdrawn into the operating position. Immediately above the fuel plates is a shell of cadmium metal sheathed with aluminum. The cadmium is in the core when the rod is in the down position. Above the cadmium is a further extension of the aluminum section and the top of the rod is a nickel-plated steel block mounted on a spring-loaded ball and socket joint which is keyed to limit its movement to tilting only. This steel top allows the rod to be lifted by an electromagnet which hangs from the top cover of the tank on a drive shaft. Above the cadmium section and below the fuel section there are slots in each of the four sides. These eight slots are about 12 inches long and about one inch wide. Their purpose is to allow water to flow over the cadmium and fuel.

PHOTO 11320

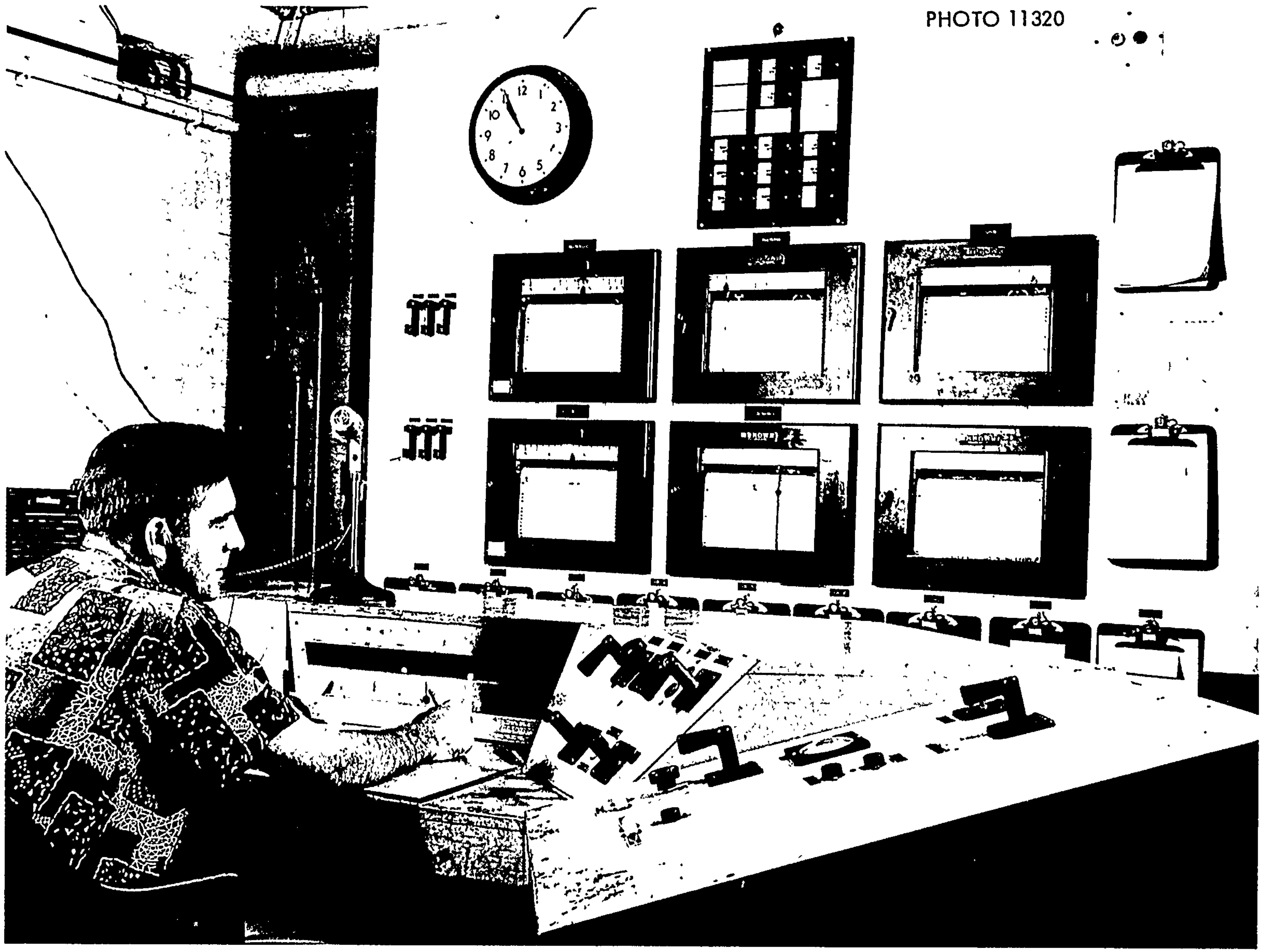

Fig. 29. The LITR Control Console. The Power Level Recorders Are Behind the Console.

The regulating rod used by the automatic control is a hollow-diameter cylindrical shell that contains strips of cadmium metal between two layers of aluminum. It does not enter the core but operates in the reflector.

The reactor tank which is 26 feet, 9 13/16 inches high is actually five hollow cylinders stacked to form a single tank. The two top sections are carbon steel. The next section is a stainless steel expansion ring. Next is a 3-S aluminum section which contains the beam hole thimbles and encloses the reactor core. Last is another carbon steel tank. The bottom of the tank is a hollow carbon steel disc which in the MTR contains lead for shielding but in the LITR is empty. The tank is supported both at the bottom and top by steel beams and thermal expansion is absorbed by the expansion ring.

The support for the core and reflector is an aluminum casting which is anchored to the tank wall. Centered in the casting is a removable 45-place grid that supports the bottom of the fuel elements and removable beryllium pieces. Eight of the 45 holes in the grid are large enough for the shim-safety rods to pass through. All but three of these are narrowed with adapters to hold the bottoms of fuel elements or beryllium pieces. Hanging below this grid is a bearing support for the shim-safety rods. Shock absorbers for the rods sit upon the bottom of the tank. A permanently stacked beryllium reflector made up of beryllium blocks whose maximum size is 2 inches by 2 inches by 8 inches is built up around the core to a height of 41 inches and enclosed on all sides by an aluminum housing. The minimum thickness of this stacked beryllium is 8 inches and occurs on the sides where the beam holes enter. It is formed around the beam hole thimbles which terminate at the core itself. (Figure 25). Since no provision was made for forced cooling of the beryllium in the stacking, the power level is limited to the present 3 megawatt level because of nuclear heating in this region which is about 0.4 watt per gram at 3 megawatt power level. At the ends of the core the stacked beryllium goes to the tank wall itself to provide a better path for neutrons to the ionization chamber thimbles which are terminated outside the tank wall. This beryllium contains two vertical holes to accommodate regulating rods used by the automatic power control. Only one of these holes is used for this purpose. The other is used for exposure of targets.

A second grid assembly fits over the tops of the fuel elements to further assure their being vertically aligned and holds the upper bearings for the shim-safety rods. This grid assembly must be removed in order to have access to the core for fuel replenishing. Figure 30 shows the finished core as it was for 500 KW operation with the upper assembly of grids removed and suspended at one side of the tank.

The hollow, flanged carbon steel disc known as the top plug which fits into the top of the tank to form a water seal also serves as a support for drive motors and shafts for the shim-safety rods and the

PHOTO 7521

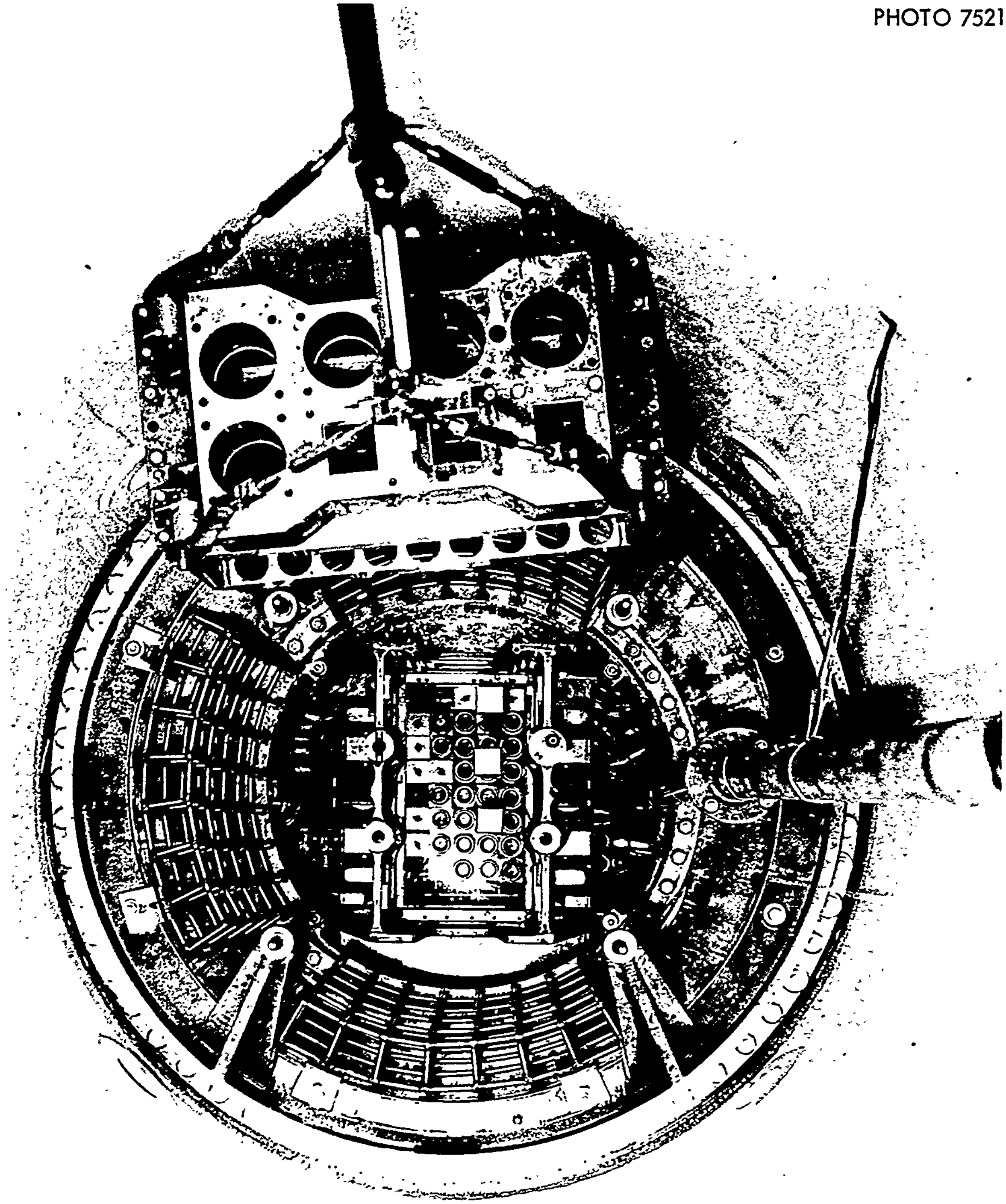

Fig. 30. Looking Down into the Reactor Tank as Assembled for 500 kw Operation. The Return Water Line from the Bottom Section Is Now 8 inches in Diameter. The Upper Assembly of Grids Is Shown Hanging from a Bracket at the Top of the Tank. The Shaft it Hangs by Is a Removable Handling Tool.

regulating or control rod. (See Figure 31.) Four support columns hold a horizontal steel frame below the top plug. This frame contains guide bearings for the rod shafts. At the corners of the frame are sockets which, fit over aligning pins anchored to a heavy steel ring which in turn, is anchored to the flanged junction of the top tank and the smaller tank immediately under it. The guide frame is spring mounted on the columns from the top plug so that actual aligning is done by the aligning pins in the tank. Four upright columns on the top plug support a platform upon which are mounted two of the shim-safety rod drive motors and the drive motor for the regulating rod. The third shim-safety rod drive motor which is not standard is mounted upon the top plug itself and requires a gear train to approximate the drive speed of the other two.

The shield around the reactor tank is built up of unmortared concrete blocks (See Figure 28) except for the outermost 1 foot layer which is of mortared concrete block covered with a layer of smooth concrete stucco. The minimum thickness is $10\frac{1}{2}$ feet. All cracks in the unmortared block are filled with sand. A layer of boron-carbide impregnated plastic was spaced at a 3-inch distance around the core tank and the 3-inch space was filled with sand. The plastic has been destroyed by radiation leaving a layer of boron and carbon. The boron reduces the number of capture gammas born in the shield. Radiation through the shield in the beam hole rooms is less than 5 mr/hr. at full power.

The water cooling system has a total volume of about 13,000 gallons. Usually only 10,000 gallons is used. About 4,000 gallons is in the reactor tank, and another 4,000 gallons is in a 7,000 gallon tank in series with the reactor. This second tank serves as a reservoir, a degassing tank, and a hold-up tank to allow decay of short-lived radioactivities such as N^{16}. The remaining 2,000 gallons is in the lines, heat-exchangers, pumps, strainers, filter, and demineralizer. The water is recirculated through the system at a rate of 1200 gallons per minute and no purging is done except in unusual circumstances.

Two 75 horsepower 1500 gpm electrically driven centrifugal pumps are used to circulate the water. Only one pump is used at a time and the other is kept in standby. In order to know that they are in working order they are used alternately for about one week periods. These pumps have stainless steel impellers and cast carbon steel housings.

Two air to water heat exchangers remove the heat from the water. (See Figure 32.) These are made up of banks of finned aluminum tubes over which air is blown by propellers operated by 40 and 10 horsepower two speed electric motors. They were designed to dissipate 2 megawatts of heat during the hot summer days (90°F), so a water to water shell and tube heat exchanger must be used during the summer to remove the other 1 megawatt at the present power level. The shell and tube heat exchanger is used during very cold weather to add heat to the system during shutdowns to prevent freezing. This is done by passing steam through the shell.

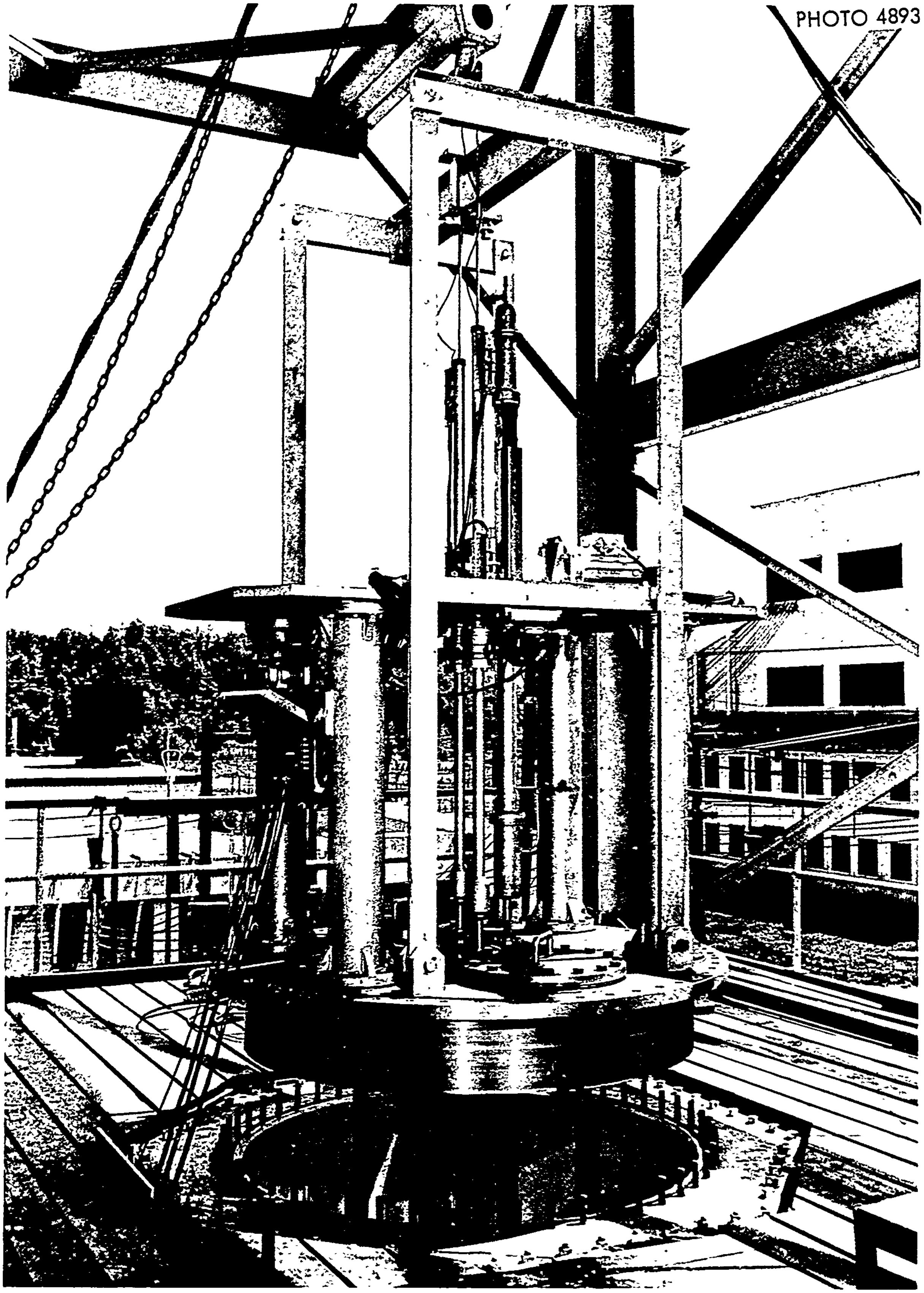

Fig. 31. A View of the Top Plug Partially Elevated. The Lead Wires to the Shim Rod and Regulating Rod Drives Are Still Connected. This Area Is Now Enclosed.

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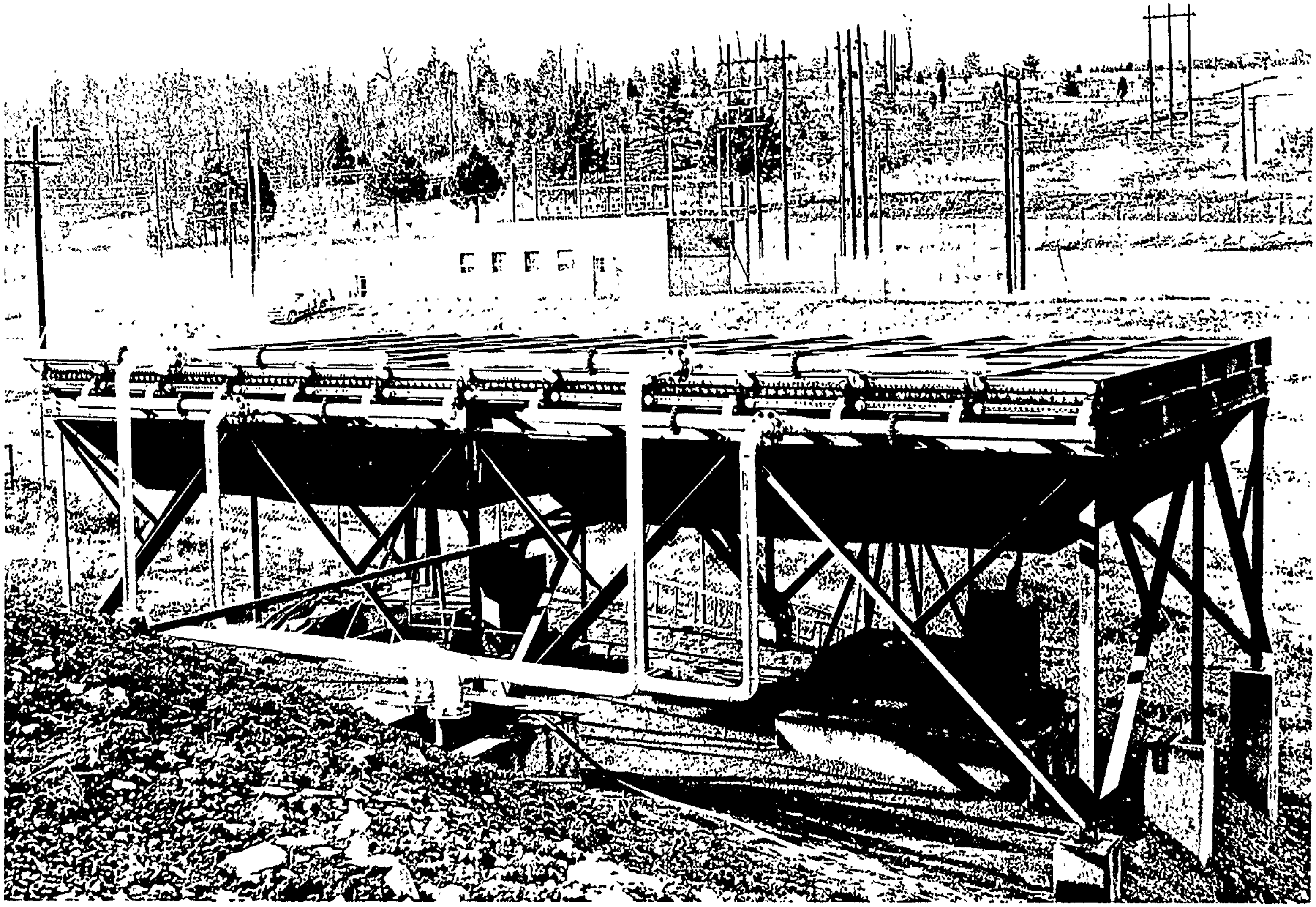

Fig. 32. The Water-to-Air Heat Exchangers Used for Removing Heat from the Reactor Cooling Water.

Since all the piping in the system is mostly either aluminum or carbon steel, enough iron hydroxide and aluminum hydroxide builds up in the water to impair visibility through the 20 feet of water in the reactor tank so that shutdown work in this region (fuel renewal, etc.) becomes very difficult. Originally the water was purged during every shutdown to improve clarity. The installation of a cellulose fiber bypass filter has completely eliminate the water clarity difficulty and actually provided greater visibility than was possible with the purging technique. Up to 400 gallons per minute can be bypassed through the filter. The life of the filter media is 6 to 8 weeks; then it begins to disintegrate. A lucite viewing plate is provided in the filter housing so that the beginning of disintegration can be seen and the media changed before it becomes distributed through the cooling system.

In order to minimize corrosion of the aluminum parts of the reactor, the pH of the water must be maintained between 5.5 and 6.5 and the specific resistance greater than 250,000 ohms. These conditions are maintained by use of a bypass demineralizer which is a system of three ion exchange resin columns capable of handling a flow of 14 gallons per minute. The three columns are in series. The first is a cation exchanger and the second is an anion exchanger, the purpose of these two being to remove most of the foreign materials from the water. The third column is a mixed bed unit which further dresses up the water and has an effluent of better than 2,000,000 ohms specific resistance. In removing ions from the water, the columns remove practically all the radioactivity from the water and thus minimize shielding for the system. The reason for not using only a mixed bed unit is that the anion exchange resin is more subject to radiation damage than the cation. By using separate primary columns, which are easily replaced, or regenerated, the life of the mixed bed resins is much prolonged with respect to regeneration and especially with respect to radiation damage to the anion component of the mixed bed. The water flow through the demineralizer is from the exit line from the air-water heat exchangers to the suction side of the circulating pumps.

Where the water lines pass through areas frequented by personnel, they are shielded by either lead or barytes concrete blocks.

The path of the water through the system is thus: Beginning at the storage tank it moves to the pump and all but the 200 to 400 gallons per minute which goes to the filter goes on through the water-to-air heat exchangers. The portion that goes through the filter bypasses the heat exchangers. After passing through the water-to-air heat exchangers all the water goes through a strainer and part or all can be passed through the shell-and-tube heat exchanger. From this point 14 gallons per minute is bled to the demineralizer and returns to the low suction side of the pump. After the shell and tube heat exchanger all the water collects into one 8-inch diameter aluminum pipe and rises to the top of the reactor tank. Just before it reaches the tank it passes a radiation monitor which shows a measure of the radioactivity of the water on a recorder in the control room. The orifice for measuring the water flow is also in this region. The water then enters the top of the reactor tank and flows downward through the core. Below the core it enters the exit water line which rises inside the tank beside the core and emerges from the tank near the top. This arrangement makes a "U" trap of the reactor tank itself and limits the amount of water that can be lost from the tank in the event of an external leak. From the top of the reactor tank the exit water line descends directly to the storage tank.

Instrumentation for the reactor controls and safeguards use the signals from four ionization chambers and a fission chamber. When the reactor is just being started up, the neutron flux in the region where the chambers are located is very low and must be monitored by the fission chamber. This is a small counter tube whose inside surface is plated with uranium enriched in U^{235}. In order to keep the fission rate in the chamber in the range of the counter circuit, the chamber is mounted on a chain drive by which it can be moved farther from the reactor core as the neutron flux increases. The counting rate recorder contains contacts that require that it be showing at least two counts per second but not be off scale in order for the shim-safety rods to be moved upward from the core. During the time that the fission chamber counter is the only instrument showing a reading, the shim rod drive mechanism is limited by a timer so that the drive can be on only one second out of four.

The next instruments that begin reading as the neutron flux increases are what are known as the Log N meter and the period meter. The Log N recorder has a logarithmic scale and becomes operative when the power level is only $\frac{1}{1,000,000}$ of the maximum power level. The period meter shows the rate of rise of the Log N. The signal to this instrumentation is from a gamma compensated boron-coated ionization chamber which can be adjusted only during reactor shutdown. Startup limitations are imposed by both the period and the Log N meters. The period meter limits initial startup rate to greater than a 30-second period during simultaneous withdrawal of the shim rods. A period as short as 7 seconds is allowed for single rod withdrawal, and a 5-second period causes automatic insertion of the rods by the drive. A one-second period causes the magnets to release the rods allowing them to fall into shutdown position. The Log N recorder contains contacts which drop out restrictions and add others as the power level increases. At $\frac{1}{1,000,000}$ of full power, it gives permission to continuously withdraw all three rods simultaneously and then requires that this permission be relinquished between $\frac{1}{1,000}$ and $\frac{1}{100}$ of full power. It also requires that the period be longer than 30 seconds when $\frac{3}{100}$ of full power is reached in manual operation or that the automatic control has begun operating if in automatic; otherwise a reversal of the rod drive is initiated. It also requires that the power level be greater than $\frac{1}{100}$ of full power when automatic control begins operating; otherwise the input demand to raise the power by the automatic control cannot be increased. When the reactor power falls below $\frac{1}{1,000}$ of full power in the event of a shutdown, a contact on the Log N resets the automatic control demand to $\frac{1}{100}$ of full power to prepare for startup.

The automatic control ionization chamber is not gamma compensated so it is not used until the power level is at least $\frac{1}{100}$ of full power. As soon as its output is greater than a set bias, it becomes effective and the automatic control takes over. This is set to occur at $\frac{1}{100}$ of full power. This chamber is boron-coated for neutron detection and is not capable of being adjusted, position wise, unless the reactor is shut down. The automatic control instrumentation uses the regulating rod to either raise or lower the reactor power so that the chamber output balances an input demand signal. The regulating rod is limited to 0.25% $\frac{\Delta k}{k}$ and cannot initiate an unsafe condition. If a positive period develops in the reactor that cannot be handled by the regulating rod, the control instruments insert the shim rods. The reverse condition cannot happen, i.e., the instruments cannot initiate withdrawal of the shim rods. In order to keep the regulating rod in its most effective position, half inserted, the operator must make small infrequent adjustments of shim rod position.

Two identical power monitors are used for power levels above 1% of full power. These take signals from boron-coated non-gamma-compensated ionization chambers which can be adjusted only during reactor shutdown. These chambers give signals to two linear recorders which show the power level from 1% to 150% of full power. On each recorder are contacts which cause a slow reduction of power by way of the automatic control if the reading exceeds 110% of full power and a fast reduction by shim-safety rod insertion if 120% is exceeded. The output from these chambers is also fed to the magnet power control and causes a reduction in magnet current as the power level increases. At 145% of full power, the magnet current is sufficiently reduced to cause the magnets to release the rods to cause a full shutdown of the reactor. This is the same system that the period meter operates through to cause a scram at a 1-second period.

The temperature differential to determine power by heat output is measured by thermocouples in wells in the inlet and exit water lines to the reactor. The water flow measurement for this determination is measured by a calibrated manometer across an orifice in the inlet water line. All other instrumentation is calibrated from the heat output.

Other instrumentation includes monitoring or provisions for monitoring the following: (1) Radioactivity of the inlet water line, (2) radioactivity and temperature of the effluent from individual fuel elements, (3) pH and specific conductivity of the water system and of the effluent from the demineralizer, (4) power load on the pumps and heat exchanger blowers.

EXPERIMENT FACILITIES IN THE LITR

The experiment openings and core spaces in the LITR are similar to but less in number than those of the MTR. Six horizontal beam holes with internal thermal neutron fluxes ranging from 8×10^{12} to 3×10^{13} n/cm^2 sec. go through the concrete shield and up to the core

Fig. 33. The Chopper Type Neutron Velocity Selector Used for Cross Section Measurements in the dE/E Neutron Region. The Beam Strength for these Neutrons Is 2×10^{12} n/cm^2 sec.

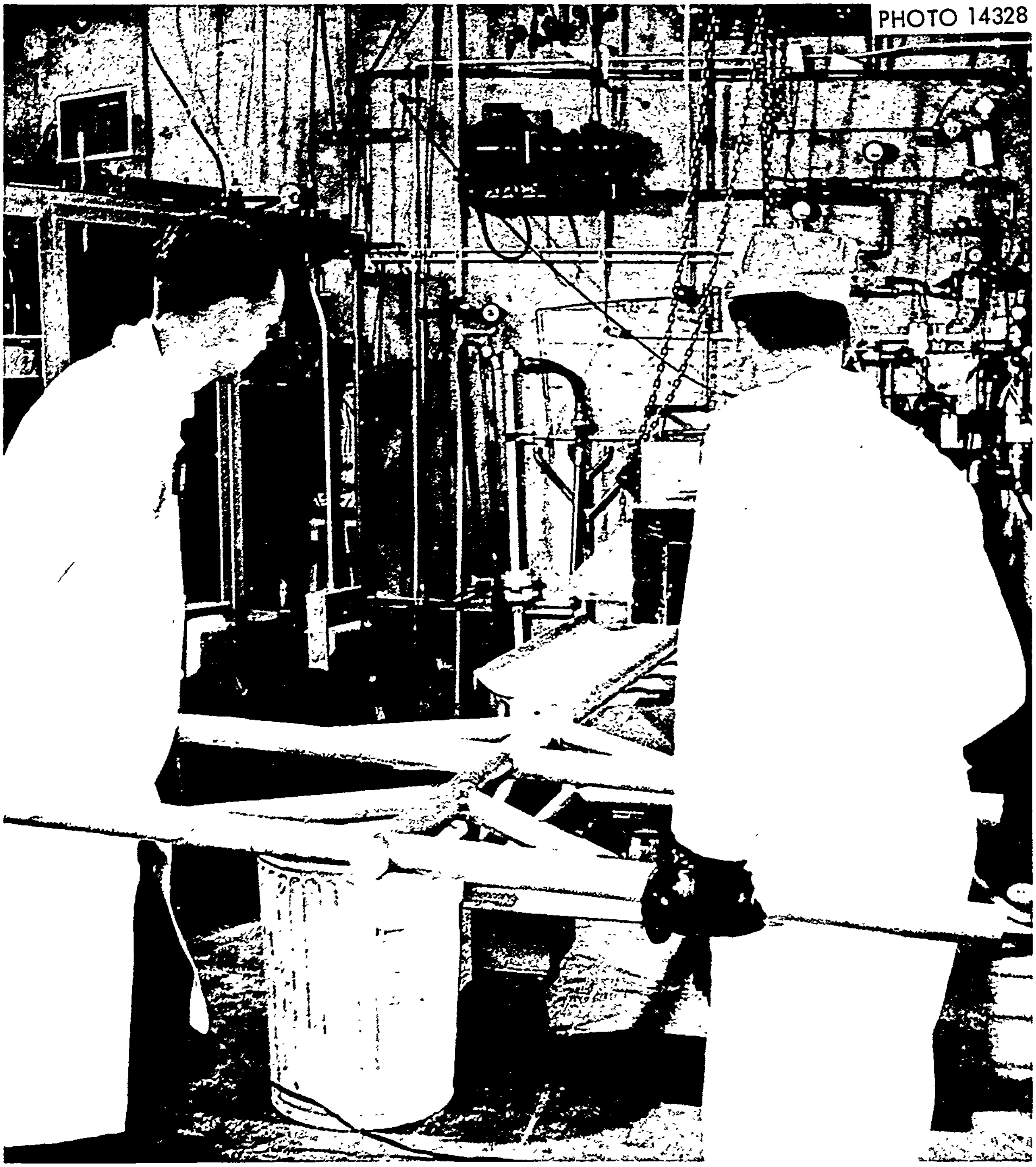

Fig. 34. A View of Operators Removing a Beam Hole Shield Plug. The Wide "T" Handles on the Tool Permit the Operators to Stand Outside the Radiation Beam from the Hole.

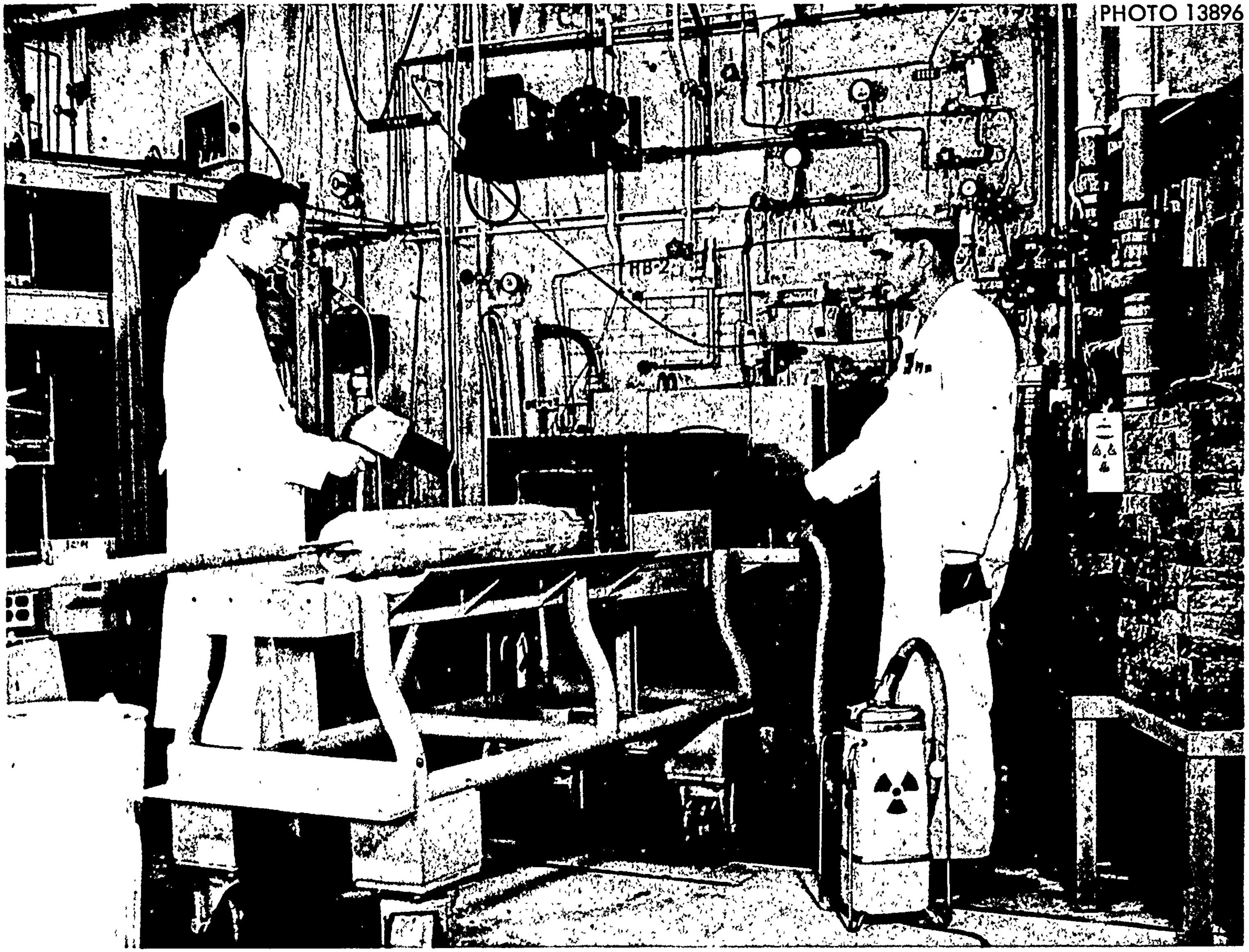

Fig. 35. Lead Shield for the Beam Hole Shield Plugs. The Vacuum Cleaner Is Used Throughout any Removal of Plugs or Experiment Pieces to Clean up Radioactive Dust.

within the tank as shown in Figure 25. These have an internal diameter of 6 inches for the portion within the reactor tank and change to 7 inches and then 8 inches in diameter in going outward to provide for stepped shield plugs to minimize radiation streaming along the plugs. The beam holes are used primarily for the exposure of materials, either static as in the case of crystal damage or dynamic as in the case of circulating loops of homogeneous reactor fuels. One beam hole is more or less permanently occupied by a chopper-type neutron velocity selector used for cross section measurements as shown in Figure 33 while the other beam holes are devoted to less permanent usages. Figures 34 and 35 show the method used to remove shield plugs from beam holes. The wide "T" handle on the tool is provided to allow the operators to stand outside the beam from the hole as the plugs are removed. Two horizontal pneumatic tubes are available which can accommodate samples up to 3/8 inch in diameter by 1 7/8 inches long.

In the core some of the removable beryllium pieces can be replaced with experiment equipment if the neutron absorption by the experiment is not excessive. In the spaces which correspond to shim-safety rod positions in the MTR but are not used as such in the LITR, access tubes can be inserted through the unused shim-safety rod holes in the top plug and on into hollow beryllium pieces in the core. These provide for irradiating small targets or pieces of equipment in thermal neutron fluxes up to 4×10^{13} n/cm^2 sec. Three removable beryllium pieces have been replaced with vertical trays made of a magnesium-aluminum alloy to provide multiple spaces for irradiating small targets in thermal neutron fluxes up to 2×10^{13} n/cm^2 sec. Four 3 3/8 inch diameter vertical holes outside the reactor tank provide up to only 4×10^{11} n/cm^2 sec. and are used primarily for ionization chamber development.

Experiments performed in the LITR require more rigid instrument monitoring than those in the Graphite Reactor because of the nuclear heat damage in the event of loss of coolant to the experiment equipment. This generally involves an automatic power reduction or shutdown of the reactor. For this reason, practically all experiments other than simple target irradiations in the water-cooled core must be equipped to send automatic signals to the reactor safety circuits in the event of excessive heat or other undesirable condition.

Operation of this reactor has for the most part been uneventful as far as the reactor behavior itself is concerned. The instrumentation has performed as designed and the control system has operated as planned. Only the usual types of instrument failures have occurred such as broken or shorted wires, tube burnout, and relay failure. Duplication of necessary functions in the instrumentation and fail-safe features have, however, prevented these from being serious.

The only really perplexing problem arose during operation at the 1000 KW power level early in the life of the reactor. This was the appearance of bubbles rising out of the core accompanied by minor power fluctuations. It was finally discovered that the water circulating pump then in use was designed to be an acid pump and was built to draw air in through the shaft seals to prevent loss of acid. This air dissolved into the water and was released as bubbles when the water was heated in passing through the core. Since the flow rate was only 300 gallons per minute, its velocity through the core was not sufficient to prevent the bubbles from rising countercurrent to the flow and causing the power fluctuations.

Reactors of this type lose fission product gases to the water from pores in the fuel element plates when operated at high powers. This does not cause a serious problem but does require that the top of the water storage tank be connected to the off-gas system since this is the only place in the system where gas can collect. Also a small amount of the water is dissociated when passing through the core and would cause an explosive mixture of hydrogen and oxygen to collect in the top of the storage tank if it were not continuously purged.

Two other lower power reactors of the LITR type are being operated as sources for shielding studies by the Physics Division. These, however, are not general purpose reactors and are usually not available for uses by other research divisions.

The Geneva Conference Reactor being operated by personnel from the Oak Ridge National Laboratory is also a reactor of this type. It, however, relies upon convection for coolant flow and cannot operate at a high power level.

CONTAMINATION CONTROL

The problems involving radiation hazards to personnel are, of course, common to both these reactors and are present where any reactor, particularly a research reactor is operated. Where there is frequent removal of materials from a reactor it is very difficult to prevent some contamination spread and some exposure of personnel to radiation.

At the graphite reactor it has been found necessary to carefully wipe all handling tools with moist cloths as they are withdrawn from experiment holes or fuel channels. Tools or pieces of equipment that cannot be wiped are drawn past a vacuum opening to remove any particles that might have been picked up within the reactor. (Figure 15). Every tool removed from the reactor is placed on paper spread upon the floor.

At the LITR it is in most cases impossible to use the wiping technique due to the high radiation coming from any open beam hole (up to 100 R/hr.) until the tools have been removed to one side. For this reason they must be carefully handled and laid upon paper until they have been decontaminated. The inside of beam holes at the LITR are not subject to an internal suction as the ones at the graphite reactor are except for the outer one foot so when a shield plug is pushed into a hole too fast, radioactive dust is blown out by the expelled air. Vacuum cleaners and suction lines from the off-gas system are used as much as possible to minimize this condition.

After any work is performed at any beam hole in either reactor or at the fuel channels in the graphite reactor, the area is carefully cleaned by mopping and thoroughly checked by radiation detecting instruments. This is in addition to the continuous radiation monitoring that is always done while any such work is in progress.

At the top of the LITR during work in the core, long handling tools, shields, and submarine lights must be frequently inserted and removed. Since the water in the reactor is radioactive, all these items must be rinsed with fresh demineralized water as they are withdrawn.

In order to keep down the spread of radioactive dust that is not concentrated enough or not radioactive enough to be read with portable radiation detection equipment, two procedures are used. One is the use of the smear technique in which small areas (about 100 cm^2) are rubbed with a piece of absorbent paper about $1\frac{1}{2}$" in diameter and the paper counted by standard beta-gamma and alpha counters. The other method is the use of x-ray films which are taped to surfaces and take radioautographs of radioactive particles. The use of the films shows the presence of imbedded particles which cannot be found by the smear technique.

In order to guard against the exposure of personnel to radiation without their knowledge, it has been found unwise to rely upon the voluntary warning from personnel handling radioactive materials, so radiation monitoring instruments that sound a loud alarm bell when the radiation exceeds $7\frac{1}{2}$ mr/hr. are located in or near all work areas in the reactor buildings. Also constantly operating air activity monitors are located about the buildings. These, too, sound loud alarms.

OPERATING AND SERVICE PERSONNEL

The Reactor Operations Department, a part of the Operations Division, is responsible for the operation and maintaining of the Graphite Reactor and the LITR. In addition to the two reactors, this department also operates a water demineralizer plant, a hydrogen liquefier, and does the handling work for a canal in which most of the radioactive materials from other sites are unloaded and stored. The personnel in the department consist of five technical men, one secretary and twenty non-technical men. The five technical men are the department superintendent, two department supervisors who report to the superintendent, and two day shift supervisors who report to one of the department supervisors. The other department supervisor serves as liaison between the Reactor Operations Department and the various research groups and aids in the preparation and operation of experiments in the two reactors. Four of the non-technical men are shift foremen and supervise the other non-technical men during 24-hour per day operation. The foremen are in direct charge of the operation of the reactors at all times. Although they have not had formal technical training, they have had sufficient training in the operation of the reactors to be competent in all physical phases of the work.

Repair work and equipment revision is done by the maintenance departments which also service other equipment and buildings.

In order to have standard radiation and contamination control, the personnel that handles the monitoring is also a central service group. These people check all work involving radiation in the reactor buildings or elsewhere to see that personnel do not become exposed to dangerous amounts of radiation and that all radioactive contamination is removed from equipment and work areas.

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